N64-81267

N-74341

Trans. No. 2

ASTRONAUTICS INFORMATION

TRANSLATION NO. 2

ARTIFICIAL EARTH SATELLITES

JET PROPULSION LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

Pasadena

SEPTEMBER 4, 1959

National Aeronautics and Space Administration
(NASA Contract No. NASw-6)

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(JPL AI/Trans-2)

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ARTIFICIAL EARTH SATELLITES:

Results of Scientific Investigations Obtained with the Help of the Third Soviet Artificial Earth Satellite

Publication of Academy of Sciences, USSR
Moscow, 1958

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Copy No. TL 137

N-74241

JET PROPULSION LABORATORY
California Institute of Technology
Pasadena 3, California
September 4, 1959

156 p refs T.E. from publ. of the Acad. of Sci. USSR, Moscow, 1958

CONTENTS

1. THE DYNAMIC EFFECTS ON THE MOTION OF ARTIFICIAL EARTH SATELLITES

L. I. Sedov

At the present time, the laws of motion of artificial Earth satellites are investigated experimentally by optical means and radio observations processed on the basis of theoretical orbital calculations and general statistical procedures relating to large numbers of measurements. Data concerning the laws of motion of a satellite in orbit are necessary to correlate scientific measurements to points in space for the purpose of forecasting satellite position and life span and for solving certain geophysical problems (revealing and accurately defining anomolies in the Earth's gravitational field, determining density distribution in the atmosphere, etc.). Data on the rotation and orientation of a satellite in space are very important for many research problems.

The theoretical calculation of a satellite's orbit and its motion around the center of gravity is connected with an analysis and calculation of forces acting on the satellite which are conditioned by the Earth's attraction, by the satellite's interaction with the atmosphere surrounding the Earth, and by the Earth's electromagnetic field. Results show that the perturbing effects of the Sun, the Moon, and meteoric particles on the motion of a satellite are quite small, and at the present time it is not necessary to take them into account.

The problems of satellite motion, taking into consideration only the Newtonian gravitational forces, have been for a long time a well-studied problem of celestial mechanics and are analogous to the problems of the motion of the Moon and the planets. The orbit of a satellite in a system of coordinates moving progressively relative to the stars and the center of the Earth is, to the extent of one turn, close to an osculating ellipse at each investigated point of this turn.

The location of an osculating ellipse having its axis at the center of the Earth can be determined by the longitude of the ascending loop Ω, by the angle of inclination of the elliptic plane to the plane of the equator (inclination of orbit i), and by the distance of the perigee from the loop ω (see Fig. 1). The major semiaxis a and the eccentricity e may be used in the capacity of parameters for the definition of the ellipse. The law of motion pertaining to one turn is almost analogous to Kepler's law of motion for an osculating ellipse.

Because of the Earth's oblateness and gravitational anomolies, the indicated parameters of an elliptical orbit are subjected to perturbations and are slightly changing with the passage of time. The perturbations are characterized by the average of secular deviations, which are nonzero, and by certain small oscillations. As is known, the basic secular effects of the Earth's oblateness lead to proportional variations of Ω and ω. For the first Soviet artificial satellites, the angle Ω varied by approximately 3 deg from east to west, and the longitude of the perigee ω descended by approximately 0.4 deg in 24 hours.

Under the influence of Newtonian gravitational forces, the potential qualitative and characteristic properties of the satellite's motion, and also that of a solid body can, insofar as the center of gravity is concerned, be traced on the basis of classic examples of lunar or terrestrial motion. The construction of a quantitative theory for satellites is essentially connected with a variety of initial conditions and with a possible difference in the satellite's moments of inertia in relation to its central axis. New essential effects are connected with the consideration of forces of the satellite's interaction with the atmosphere and the Earth's electromagnetic field.

A large number of papers (Refs. 1-5) dedicated to the study of problems involving air resistance and its effect on satellite motion have made some conclusions concerning the influence of these forces. However, until recently, a fundamental difficulty has been the absence of data pertaining to properties of the atmosphere at high altitudes.

Since the linear velocities of the rotation of the satellites in relation to the center of gravity are small in comparison with the velocity of the center of gravity in relation to the atmosphere, the influence of rotation becomes essential only through the changing orientation of the satellite in relation to the velocity vector of the center of gravity.

In published works the influence of higher dynamic forces has been analyzed on the assumption that the effect of the air is reduced to the resistance force W, which is directed against the velocity of the center of gravity. The definition of the resistance W is reduced to the definition of the coefficient C_x in the formula

$$W = C_x \rho \frac{Sv^2}{2} \tag{1}$$

where ρ is the density of the atmosphere in the vicinity of the satellite's flight, S is the overall area of the external surface, and v is the velocity of the satellite.

At the present time, the coefficient C_x is determined theoretically by calculations employing methods of molecular aerodynamics. Generally speaking, this coefficient depends on the atmospheric temperatures, the satellite's velocity, and the interaction of molecules and atoms of the atmosphere with particles which make up the surface of the satellite. At the same time, the magnitude C_x can essentially depend on the geometric form and orientation of the satellite in relation to the velocity vector of the center of gravity. A theoretical analysis which was conducted in regard to the Soviet satellites, taking into consideration information on the satellites' rotation around the center of gravity, leads to the numerical values of C_x, which may differ from the initial values or change in the course of time to the extent of 30, 60, and 30%, for Sputniks I, II, and III, respectively.

During the movement of a charged satellite through a plasma, additional resistance is formed which, by large negative charges (about 30 volts) in the presence of a satellite of small dimensions and at high altitudes, can increase C_x by two times (Ref. 6). In the case of satellites with large dimensions, this effect apparently does not exist. Evaluations which were carried out indicate that the resistance force which is stipulated by the interaction of the satellite with the Earth's magnetic field is not essential.

At altitudes of about 230 km, the resistance force is very small since the atmospheric density ρ is small. According to recently obtained data, the density of such altitudes is on the order of 3×10^{-13} g/cm^3. In the case of Sputnik III, the resistance force in the perigee is on the order of W = 4 grams and $W/G \approx 3 \times 10^{-6}$ (where G is the weight of the satellite).

Published theories on satellite motion which take resistance into consideration were developed with the assumption that C_x = constant and that the density decreases with altitude according to a given law. Particularly, the following law of density drop is widely used in practice:

$$\rho = \rho_0 e^{\frac{z - z_0}{H}} \tag{2}$$

where ρ_0 is the density at the altitude z_0, and z is the altitude reckoned by a standard from the surface of the Earth's sphere. The quantity H may be considered a constant for the isothermic regions of the atmosphere.

Observational data and calculations of resistance for nonoriented satellites of nonspherical shape indicate the necessity of taking into account the variation C_x as a result of rotation of the satellite in relation to its center of gravity.

An analysis indicates that the presence of the resistance force W leads to secular variations of the orbit which are expressed by the decrease of eccentricity and the drop of the perigee for an osculating ellipse, whereby a decrease in the period of revolution T occurs. The perigee drops slowly and the apogee drops more rapidly.

If the difference in altitudes of the apogee and perigee is considerably larger than H, then the initial retardation takes place in a small region around the perigee, where the density is greatest. It should be mentioned that in this case the effects of aerodynamic moments on the rotation of the satellite are also exerted in the vicinity of the perigee. We assume that a satellite is limited by the plane of rotation and is dynamically symmetrical in relation to the axis of rotation. In the absence of perturbing moments relative to the center of gravity, it is known that the moment vector of the quantitative movement remains constant while the rotation axis of the satellite completes a regular precession around the moment vector of the quantitative movement.

It is obvious that the aerodynamic forces create a small perturbing motion. The resultant of aerodynamic forces applied to the axis of the satellite's rotation--other things being equal, this occurs for a mirror-position location of the axis of rotation of the satellite in relation to the plane π, which passes through the velocity vector of the center of gravity and the moment vector of the quantitative motion--is expressed by vectors which happen to be specular images of each other in relation to the plane π. Hence it follows that the moment vector of aerodynamic forces in relation to the center of gravity, over a period of one precession, is perpendicular to the plane π. If the essential values of aerodynamic moments are effective only in the region of the perigee, then it follows from the preceding considerations that the secular part of the perturbed rotation represents a slow precession of the moment vector of quantitative motion relative to the tangent to the orbit at the perigee. This assumption was also established in Ref. 7 by means of a more detailed investigation of perturbed motion.

The analysis shows that in the case of the second satellite the perturbing moments of gravitational forces are comparable to aerodynamic moments. As is known, the gravitational moments cause a precession of the moment vector of the quantitative movement with reference to a standard of the orbital plane.

In Ref. 7, the simultaneous effect of aerodynamic and gravitational moments as well as the specification of the nature of perturbed motion, with relation to orbital regression, were also made subject of discussion.

The interaction of the Earth's magnetic field with the rotating metallic body of a satellite generates Foucault currents in the body of the satellite and precipitates retardation moments in the rotation of the satellite near the center of mass. This must be taken into consideration when investigating the rotation of a light, non-stabilized satellite. Obviously, in some cases, the law of rotation which was altered under the influence of the magnetic field can, through an alternate orientation, exert an influence on the magnitude of resistance and hence on the life span of the satellite.

Since the moments of inertia relative to the central axis of the carrier rocket of Sputnik I vary significantly, it may be assumed, as a result of the casual character of the initial disturbances, that the angle of nutation must be close to 90 deg. The resulting motion resembles a condition of "tumbling". Observations confirm this conclusion. Analysis of experimental results of the investigation of solar radiation permits some conclusions to be drawn on the movement of Sputnik II around the center of mass in the beginning of its existence (November 3, 1957). The parameters of motion around the center of mass proved to be as follows: the precession period is 206 ± 10 sec; the rate of precession is 1.7 deg/sec; the angle of nutation is 86 ± 1 deg; the angle between the vector of the kinetic moment and the orientation towards the Sun is 90 ± 5 deg.

Optical observations of the variations in brightness of Sputnik II were conducted at various locations in January, 1958. The strong variation of brightness intensity can easily be explained by a state of movement near the center of mass which resembles tumbling. The period of precession of the satellite will equal twice the period of the satellite's brightness variation, and optical observations of Sputnik II have confirmed that the indicated period exists. According to optical observations of Sputniks I and III, the precession period of their respective carrier rockets lasted, respectively, about 80 sec and less than 15 sec.

The orientation of the third satellite was determined with the help of data obtained through the processing of readings taken from instruments which fix the position change of the magnetometer housing per unit of time. Preliminary results have shown that the motion pattern of Sputnik III was also close to a pure tumbling pattern. The precession period appeared to last 125--135 sec. The period of the satellite's own rotation proved to be considerably longer.

Orbital data of the satellites were determined on the basis of processed results from a large amount of observation. In the case of Sputnik I, 60,000 radio measurements and 400 optical observations were processed. In the case of Sputnik II, 12,800 radio measurements and 2,000 optical observations were made. In addition, 124 photographs were utilized. By July 7, 1958, 52,750 radio measurements and 1,260 optical observations were processed relating to Sputnik III.

These data were processed by electronic computers. Table 1 presents the parameters of the orbit at the beginning of motion.

The orbits of satellites which passed through the upper atmosphere are very convenient for observation, except for small areas in the vicinity of the poles. Figure 2 presents the graphs of the variations of the satellite's rotation period around the Earth. Figure 3 gives the graphs of the variation of the perigee h_{min}, and in Fig. 4 the variations of the apogee H_{max}, for each of the three satellites are indicated.

The processing and prediction of an orbit are very complicated and always difficult operations, since it is necessary to process large numbers of measurements and maintain great accuracy. A short time after data from measurements have been obtained, it becomes necessary to make a prediction. Of significance in facilitating this is a special method of processing observational data which allows one to obtain accurate ephemerides rapidly. Methods for accurate operational predictions were worked out and used successfully in practice.

Observation data on the evolution of the satellite's orbit can be used to determine the atmospheric density. From the equations of motion of the satellite's gravity center, it is possible to derive the following approximate formula for ΔT variations of the rotation period of the satellite for one turn:

$$\Delta T = - \frac{3\pi S a^2}{\sqrt{\mu m}} C_x \, \rho_\pi \sqrt{\frac{2\pi H}{e}} \, f\left(e, \frac{H}{ae}\right) \tag{3}$$

where μ equals 3.98600×10^{20} cm^3/sec^2; m is the mass of the satellite; a is the major semiaxis of the osculating ellipse; $f\left(e, \frac{H}{ae}\right)$ is the known function of its arguments; e is the eccentricity determined for each moment of time from the orbital data; and $\rho\pi$ is the density at the perigee.

With small values of the eccentricity e and values of the parameter $H/ae < 1/4$, the asymptotic value of the function f equals one (Ref. 8).

The volume ΔT, the eccentricity e, and the semiaxis a are determined from observations, and the value H can be evaluated through the temperature of the atmosphere in the vicinity of the perigee. By taking advantage of these and theoretical data pertaining to coefficient C_x, it is possible to determine the density $\rho\pi$. The accuracy of such a calculation depends on the reliability of the adopted values for C_x and H.

It is also possible to determine the volume H with the help of orbital data; however, for this purpose, it is necessary to determine the extremely small volume of $\Delta\ h_{min}$ with great accuracy, which makes it difficult to obtain a reliable result.

When H = 25 km and $C_x = 0.525$, the following values of density were obtained for h = 225 km (Refs. 8 and 9):

$$\rho\pi = 3 \times 10^{-13} - 4 \times 10^{-13}\ g/cm^3$$

The obtained density values should be regarded as mean air density values at the latitude of the perigee from many points uniformly distributed along a parallel.

In calculations which were carried out by using data on orbit evolution, attention has been paid to the systematic reduction of the fixed altitude of the product $C_x \rho_\pi \sqrt{H}$ during the perigee transitions, which is a result of the orbit regression from day to night. This effect has been noted in the case of all satellites. Hypotheses have explained this to be due to a drop in atmospheric density at an altitude of 225 km during the transition from day to night.

The above indicated values for density agree well with some data on density obtained from rocket measurements.

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Table 1. Dynamic Effects on the Motion of Artificial Satellites

	Sputnik I	Sputnik II	Sputnik III
Period of rotation about the Earth T, min	96.17	103.75	105.95
Minimum altitude h_{min}, km	226-228	225	226
Minimum altitude h_{max}, km	947	1.671	1.881
Orbit inclination 1, deg	65°.129	65°.310	65°.188
Daily longitude departure of ascending node $\Delta\Omega$, deg	-3°.157	-2°.663	-2°.528
Daily shifts in distance of perigee from Angle $\Delta\omega$, deg	-0°.432	-0°.407	-0°.326
Daily period variation ΔT, sec/24 hrs	1.8	3.08	0.75

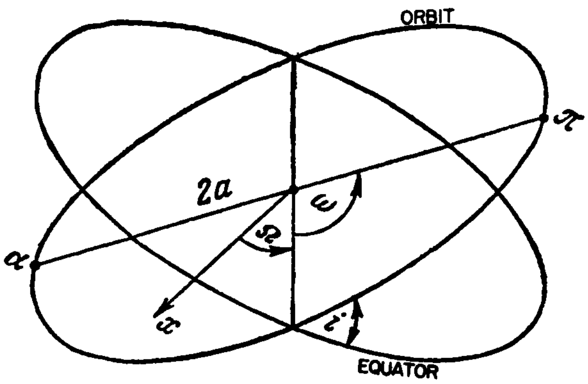

Fig. 1. Diagram for the Determination of Orbit Position

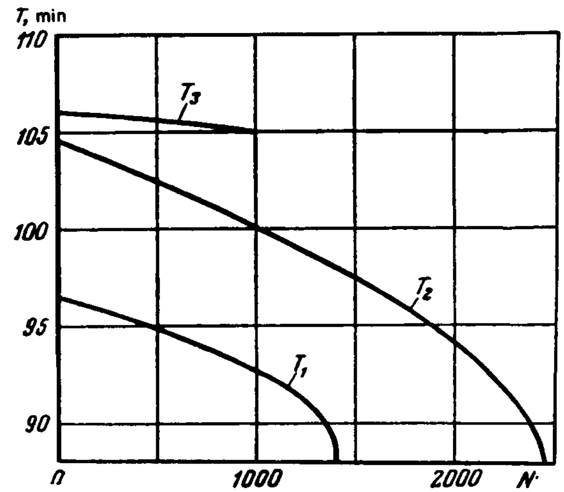

Fig. 2. Period of Satellite Revolutions in Relation to the Number of Turns

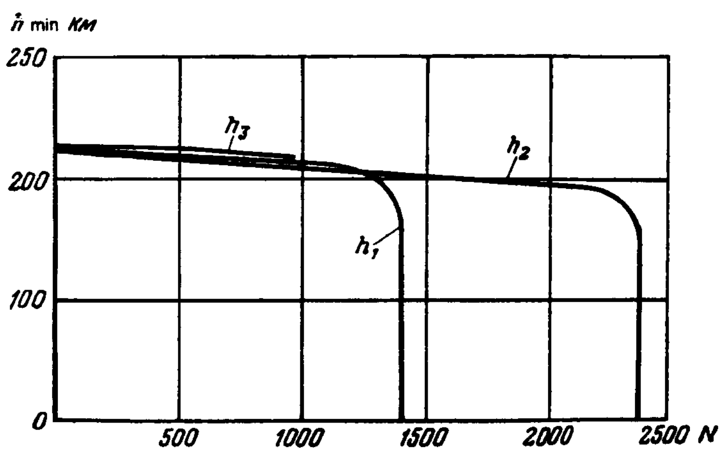

Fig. 3. Height of Satellite Perigee Depending upon Number of Turns

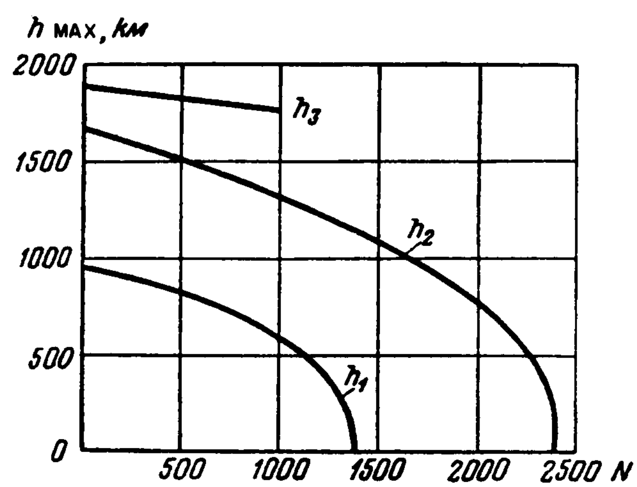

Fig. 4. Height of Satellite Apogee Depending upon Number of Turns

2. CERTAIN RESULTS OF MEASUREMENTS OF THERMODYNAMIC PARAMETERS OF THE STRATOSPHERE USING METEOROLOGICAL ROCKETS

E. G. Shvidkovsky

The program of rocket research of the upper layers of the atmosphere which is being conducted at present in the Soviet Union includes the study of the thermodynamic parameters of the stratosphere (the region of the atmosphere which stretches from the tropopause to the region of minimum temperature, which is located at an altitude of around 80 km) in the polar, arctic, and antarctic regions and in the mean latitudes of the Soviet Union. Arctic investigations are being conducted on Heiss Island (Franz-Josef Land Archipelago); antarctic investigations of the lower and mean stratosphere are conducted aboard the diesel-electric ship "Ob," which is completing various works under the program of the IGY.

The accumulated materials of experimental observations have not yet been completely processed. Particularly, this report does not include information obtained from the ship "Ob." Therefore, this report should be considered as of a preliminary character.

The scheme of the rocket experiment adopted for stratosphere investigation during the IGY consists, in general, of the following. Atmospheric temperature is measured by resistance thermometers in the form of thin tungsten filaments. Pressure is measured by manometers adjusted to the necessary range of pressure change. Measuring elements of the instruments are mounted on a slender spire which is fastened to the head section of the rocket. The remaining measuring equipment is located in various compartments of the head section.

At a predetermined altitude the head section, with the measuring apparatus, separates from the body of the rocket and descends by parachute to Earth. Basic measurements are usually made during the period of descent. Instrument readings are transmitted to Earth by means of radio telemetering systems and are recorded on photographic film.

The theory of the methods for measuring temperature and pressure in the experiments described above introduces a number of questions relating to the problem of interaction of the instruments with the surrounding environment. This theory permits the calculation of the parameters in free atmosphere which are strongly influenced by the movement of the head section of the rocket. At the same time, the interaction of the instruments with the atmosphere is changed from conditions corresponding to a free, regular flow to a flow tending toward conditions of continuous aerodynamics.

Processing of telemetering data gives pressure and temperature values which are fixed by the instruments as time functions. The utilization of the equation for the state of an ideal gas, a barometric formula, the laws of molecular and gas dynamics, and the results of preliminary laboratory tests makes it possible to find the pressure, temperature, and density of the free atmosphere as a function of altitude. At the same time, other important factors, e.g., radiation transfer and the deviation from thermal and dynamic equilibrium between the instruments and the gas directly adjoining them, are also taken into consideration.

The design and processing of the experiment do not, in principle, require tracking the trajectory of the rocket head section. The system is almost entirely suitable for the accumulation of systematic data in the fields of thermodynamic parameters of the free atmosphere, with an altitude restriction to the region of the middle part of the stratosphere.

During the investigation of the upper stratosphere, the increasing effect of rarefaction of the atmosphere leads to a sharp increase of side effects and makes trajectory tracking essential. In the opposite case, experimental errors in determining the parameters of the state of the atmosphere become excessively great. In these cases, tracking is accomplished by optical and radio methods.

Prior to the IGY, parameter measurements of the state of free atmosphere up to an altitude of 80 km were conducted in the middle latitude of the territory of the Soviet Union. Since these results were published (Ref. 1) in the form of mean distribution curves of temperature, pressure, and density during the fall-summer season, we shall discuss them briefly.

First of all, it should be mentioned that on all levels of altitude within 80 km of the Earth's surface a good correspondence can be observed between the thermometer readings. Such a comparison was made by tracking the head section of the rocket. This achieved agreement was the experimental basis for starting investigations of the lower and middle stratosphere without trajectory tracking, which simplified the experiment considerably. The reliability of the obtained data is supported by the fact that the error of individual temperature measurements at an altitude of 75-80 km does not exceed 15°C. The temperature curve which we have obtained closely resembles the known curve of temperature distribution in the stratosphere as proposed by the U.S. However, there are several differences in the basic extreme points of both altitude and temperature values.

In the following part of this report, we will examine the characteristics of seasonal changes of the temperature field in the middle and lower stratosphere, relying on the results of the rocket investigations in the arctic and in the middle latitudes of the Soviet Union. For that reason, the material presented hereinafter will pertain to altitude regions of up to 45-50 km.

We will not present any pressure distribution curves because of their insignificant value. However, we will mention that the general appearance of these curves gives the basis to the assumption that the pressure decreases during the seasonal change from summer to winter. The pressure changes in the north are expressed somewhat more strongly than those in the middle latitude.

In Figs. 1 and 2 are presented the temperature regions as recorded for several months on Heiss Island and in the middle latitudes (of the Soviet Union). An analysis of reduced data permits us to make a series of preliminary conclusions.

The temperature of the lower stratosphere in the altitude region of 20-25 km decreases with the transition from summer to winter. The lowest temperatures occur during the months of December and January.

In the altitude region of 40-50 km this rule does not apply. This is the region of the stratospheric maximum temperature and, as can be seen from the curves, it is situated higher in the north than in the middle latitudes.

If we would compare the curves relating to the northern and middle latitudes, we might note that an almost isothermic layer in the polar regions reaches a higher altitude from the tropopause than in the middle latitudes. This indicates that, between October and January, the altitude of the lower level of the atmospheric layer increases from 26 to 32 km with the positive temperature gradient in the polar region. In the middle latitude a corresponding change takes place within the limits of 21-26 km.

The mentioned circumstances are possibly connected with the fact that in the polar regions the ending of the polar night affects the temperature of the middle stratosphere so that the temperature curve which is characteristic for the latitude of Heiss Island already gives evidence of the heating of the stratosphere under the influence of sunlight at an altitude of 40 km. Owing to this effect, the temperature gradient for the north, in the region up to the stratospheric temperature maximum, changes from 1.5 to 5.5 deg per km during the transition from the beginning to the end of the polar night. Contrary to the above-mentioned phenomena, the temperature gradient of the indicated region remains almost unchanged and equal to about 2 grad/km in the middle latitudes.

Temperature fluctuations in the middle latitudes near the stratospheric maximum lie between 260-280°K. In the north, they are confined apparently to within 270-310°K. Thus, the mean stratosphere in the northern regions is not only somewhat warmer than in the southern regions, but also the seasonal fluctuations of temperature in the mean stratosphere of the regions which are located beyond the polar circle are expressed more strongly than in the middle latitudes.

The following fact speaks in favor of the assumption that the described changes of the temperature field in a given place are of a seasonal character and do not occur simply as a consequence of synoptic changes. We will concern ourselves with the character of the annual temperature variations at various altitudes of the stratosphere. In Fig. 3 are presented the corresponding results for the mean latitudes. In the lower stratosphere, at altitudes of 26-34 km, a distinctly expressed temperature maximum is observed which takes place during the summer period. These curves are like fluctuations having an annual period. For the indicated altitude region the amplitude of the fluctuations equals approximately 13 deg. With the increase of altitude the amplitude decreases insignificantly, and, in the regions of 45-50 km, it equals approximately 10 deg. We might mention here that if, at an altitude of 45-50 km, the temperature maximum in the middle latitudes coincides favorably with the moment of the summer solstice then, at lower altitudes of from 26-34 km it occurs during July. The given results for each month are not average values obtained from large amounts of observational data, as is the case in meteorology; to a certain degree they preserve the outlines of separate measurements. Consequently, the observation of annual fluctuations of the temperature in the stratosphere cannot be of a pure synoptic nature but should reflect the seasonal variations of the condition of the atmosphere.

From the results of separate rocket probes, shown in Fig. 4, it is evident that the temperature field in the lower and middle stratosphere can be thin. The presented curve was obtained at Heiss

Island. A similar temperature distribution was more than once observed during separate rocket launchings.

Though the generally observed temperature changes are small and reach values of 10, 15, and sometimes 20 deg, they lie outside the error limits for the experiments. The cause of such temperature stratifications may be the presence of a large-scale turbulence. However, the temperature stratifications may also be of a more stable character. In any case, the experiment suggests that the hypothesis concerning a single and double tropopause is too approximate. Actually, in many cases the temperature field is of a more complicated character above the tropopause; this is due to series of extremes in the altitude function.

The above-described peculiarities of the temperature field of the lower and middle stratospheres require further specifications, of course. This can be achieved with a great amount of experimental data and a more detailed analysis of such data. There is no doubt, however, that we have here a series of problems which require serious attention.

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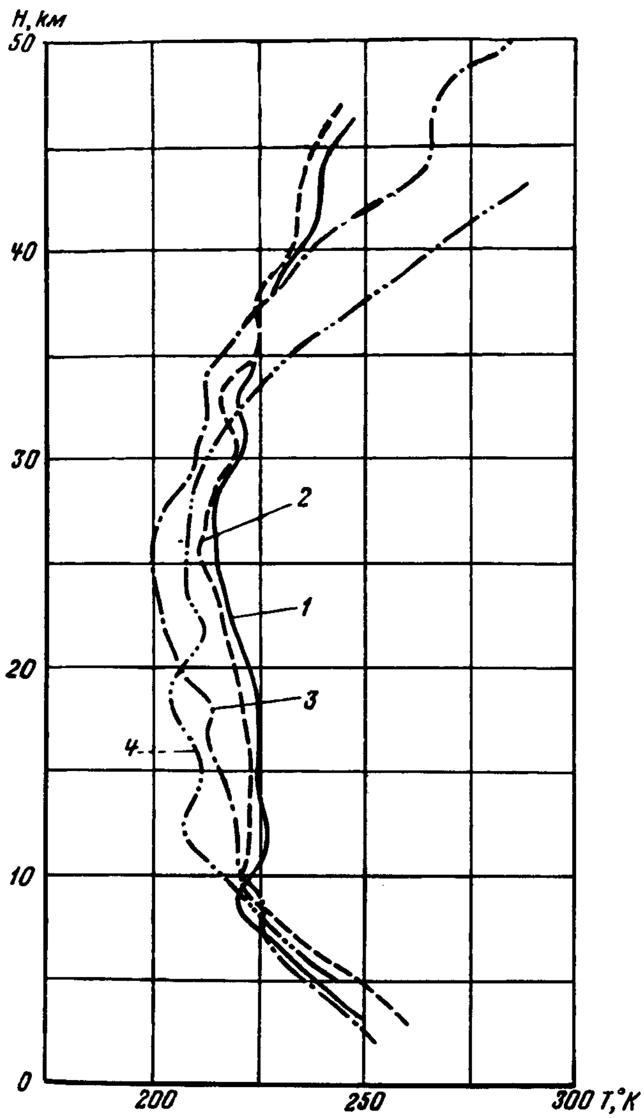

Fig. 1. Temperature Distribution According to Altitude Above Heiss Island (1-October 1957; 2-November 1957; 3-December 1957; 4-January 1958)

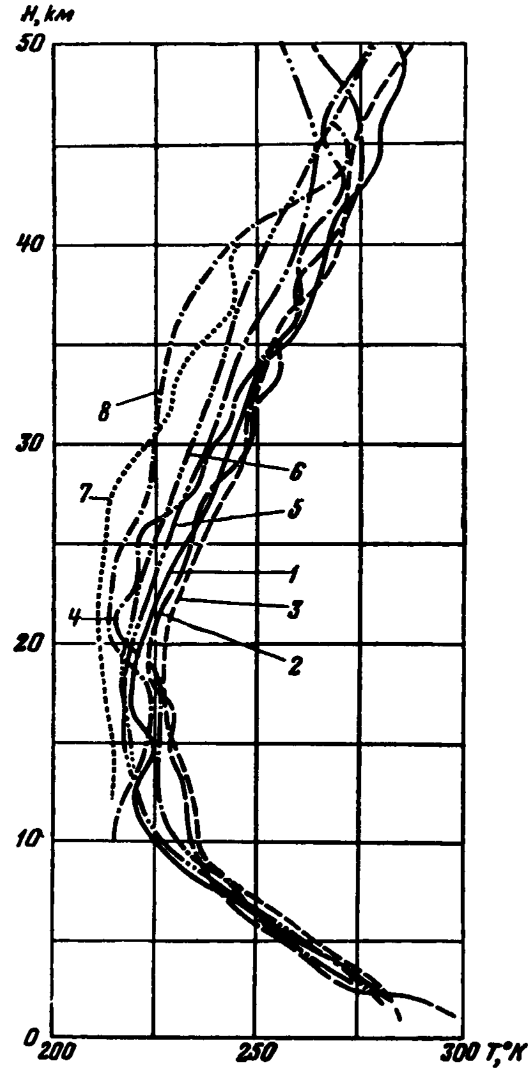

Fig. 2. Distribution of Temperature According to Altitude in the Middle Latitudes (1-May 1957; 2-June 1957; 3-July 1957; 4-August 1957; 5-September 1957; 6-October 1957; 7-December 1957; 8-February 1958)

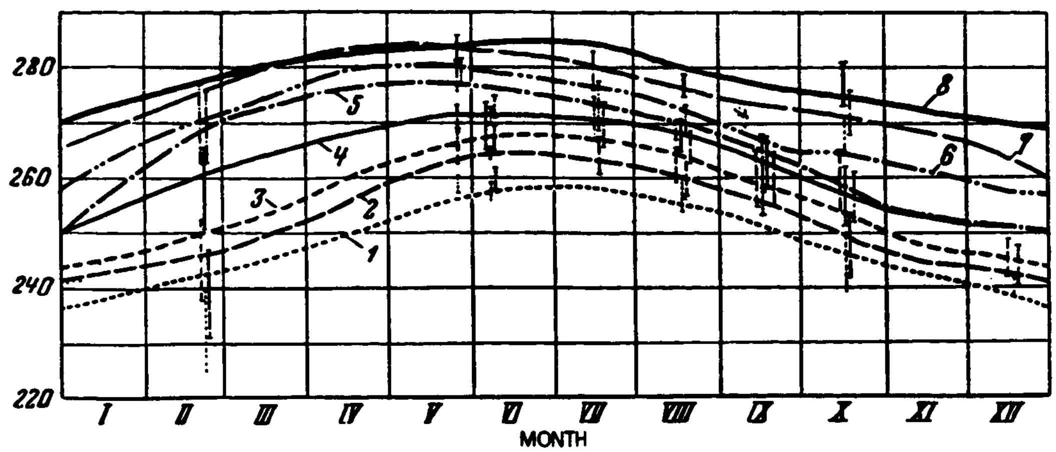

Fig. 3. Annual Variation of Temperature in the Stratosphere, Middle Latitudes (Roman numerals at botton of figure refer to months of the year) (1-36 km; 2-38 km; 3-40 km; 5-44 km; 6-46 km; 7-48 km; 8-50 km)

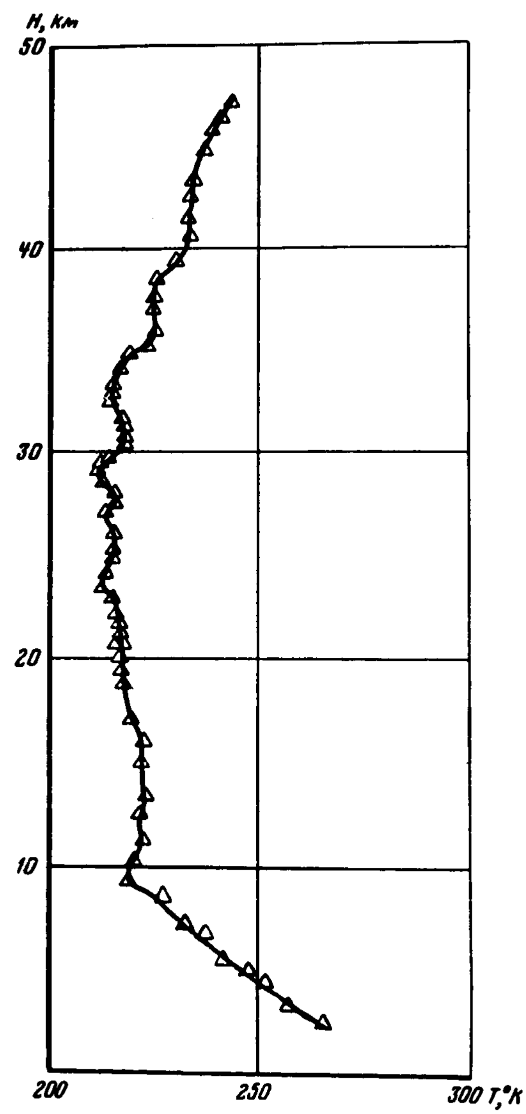

Fig. 4. Temperature Field above Heiss Island According to Data from Rocket Probes (Launched 10:55 a.m., November, 1957; Earth Temperature T_0 = 254°, 6K; Data Obtained During Descent)

3. DISTURBANCES OF THE GAS ENVIRONMENT CAUSED BY A FLIGHT OF A SATELLITE

B. A. Mirtov

During flight through a rarefied gas environment, a satellite generates fluxes of molecules which travel with the satellite at high velocities in relation to the molecules of the surrounding environment. We should distinguish two types from among these fluxes: fluxes of molecules which are discharged by the satellite itself (due to superficial distortions and leaks from the inside of the satellite) and fluxes of molecules of the environment which are bounced off the satellite in accordance with the laws of elastic collision. The first fluxes possess a mean molecule velocity of 8.5--9 km/sec; the second fluxes possess a mean molecule velocity of 13--16 km/sec. Owing to these fluxes, the environment surrounding the satellite undergoes perturbations which are caused, first, by the effect of violation of their density and, second, by the fact of thermochemical reaction and ionization which takes place during the collision, since the molecules which are produced by the satellite possess sufficient energy for this purpose. Furthermore, since the velocity of the satellite exceeds the thermal velocity of the molecules of the environment, a "rear cone" of molecular umbra is formed in the wake of the satellite which can be penetrated only by very fast moving molecules of the surrounding environment.

Therefore, when conducting such satellite experiments as the measurement of the ion contents, the ion concentration, and the air density, it is quite possible, for the above-mentioned reasons, to record false results which do not correspond to the actual state of the measured parameters of the undisturbed atmosphere. The purpose of this paper is to evaluate some disturbing factors which might have an effect on the measurements of the indicated values.

A. Preliminary Remarks

1. During the collision of a molecule escaping from the surface of the satellite with a practically stationary molecule of the environment, the first molecule loses an average of one-half of its velocity if the collision is deflective; during a non-deflective collision, the velocity decrease is even greater. Therefore, this molecule will either depart from the satellite if the collision occurs near the satellite and the molecule has time to catch up with the head section of the satellite, or it will settle again on its surface.

2. During the evaporation of the molecules from the surface of the satellite, densities of the evaporating molecules can be such that, in spite of their enormous number, they will not collide with each other. Their trajectories roam in straight lines until a collision with molecules of the surrounding environment occurs. This condition is well-known from experiments with clusters of molecules (Ref. 1) and exists even in the event of very high evaporation densities.

3. If the evaporation of molecules emanates from a stationary body, then the period of free coasting will be the distance which the molecule travels from that body to the first collision with a stationary molecule of the environment. This does not apply if the

evaporating body itself is in a state of rapid motion. In such a case, the molecule which departed from the forward hemisphere has less distance to travel before it encounters its first collision, since the body itself follows the departing molecule. We will define the distance which the molecule will eventually reach after its departure from the moving body as "escape" and we will define it as λ^*. We will define the density of collisions at various distances from the moving body by the escape value λ^* and not by the mean free pass.

It can be proven by the following correlation that the escape is related to the length of the period of a free run of the environment through which the satellite travels:

$$\lambda^* = k\lambda_{sr} \text{ (mean free pass)} \tag{1}$$

The coefficient k depends on the velocity of the satellite v_c, on the velocity of the departing molecules v_m, and on the angle φ, which is composed of the velocity vectors of the satellite and the molecules. In general, this function can be sufficiently well approximated by the following expression:

$$k = \frac{v_M}{v_M + v_c} \cos^2 \psi + \frac{v_M}{\sqrt{v_M^2 + v_c^2}} \sin^2 \psi \tag{2}$$

where, for the angle ψ, the following standardization is introduced:

$$tg^2\psi = \frac{4\varphi^2}{\pi^2 - 4\varphi^2}$$

For extreme values ($\varphi = 0$, $\varphi = \frac{\pi}{2}$) formula (2) will read correspondingly:

$$k_0 = \frac{v_m}{v_m + v_c} \tag{3}$$

$$k_{\pi/2} = \frac{v_m}{\sqrt{v_m^2 + v_c^2}} \tag{4}$$

In the case of evaporating molecules, when $v_c \gg v_m$, expressions (3) and (4) practically coincide; they differ in the case of molecules deflected from the satellite with large velocities. In this case,

$$k_0 = k_{\pi/2} \sqrt{2} \; (v_c = v_m)$$

In order to simplify the calculations, we will consider that equation (3) will fulfill the requirements in every case. It should be mentioned that when $v_c = 0$ (stationary body) equation (2) will yield $k = 1$ and, consequently,

$$\lambda * \equiv \lambda_{sr}$$

4. We will now make a final remark: In a free atmosphere, at altitudes of 200--700 km, the Maxwell distribution of molecules vs velocities is preserved according to velocities, and the free run of molecules at these altitudes is determined by the usual exponential law.

B. The Influence of Evaporating Molecules

In addition to the increased concentration of molecules around the satellite, the evaporating molecules, which possess an energy of about 10 ev, may alter the composition of the surrounding gas, since they have sufficient energy to cause the disassociation of an encountered molecule or ion during a collision, or to enter into a chemical union with that molecule. Therefore, taking into consideration the above-mentioned facts, we will discuss the question of how the concentration of molecules and the frequency of their collisions in the vicinity of the satellite change as a result of gas desorption from its surface.

With increased distance from the satellite, the concentration of evaporating molecules (in units/volume) should decrease for two reasons:

1. As a result of the influence of the law of collisions which separates the molecules from the flux.

$$N_x = N_0 e^{-\frac{x}{\lambda^*}} \tag{5}$$

   where N_0 is the number of molecules which have departed from the surface of the satellite per unit of time, N_x is the number of molecules, from the original number, which have traveled the distance x without collisions, and λ^* is the escape.

2. As a result of volume increase, which should be due to the evaporating molecules. (Actually, at distances

close to the surface of the satellite, the density will correspond to the law of dilution, $1/2 \left(1 - \sqrt{1-(r/R)^2}\right)$; however, for our evaluations we may accept the law $1/R^2$ without committing too much of an error.)

Let us assume that the satellite is a sphere having the radius R. We will investigate the additional concentration created by the evaporating molecules in a thin spherelike envelope d located at distance x from the surface of the satellite. The additional concentration of such molecules in the envelope equals

$$\rho_x = \frac{N_x d}{v_m V} \tag{6}$$

After calculating the volume of the envelope V and substituting it in equation (6), we obtain, with consideration of equation (5),

$$\rho_x = \frac{N_0}{4\pi v_m} \frac{e^{-\frac{x}{\lambda^*}}}{(R+x)^2} \tag{7}$$

When R, N_0, v_m, v_c, and λ_{sr} are known, it is possible to calculate, with formula (7), the concentration which is created by the evaporating molecules on the given distance x from the satellite. This includes all molecules which have penetrated into the envelope d.

Since the evaporated molecules are distributed along radial lines and very seldom collide, they can hit the measuring device only from that solid angle by which the outlet opening of the instrument "sees" the irradiating surface. If no collisions would occur between the radiating molecules of direct action and those of the environment, then the corresponding orientation of the entrance opening of the device would be fully capable of protecting the device from "radiating" surfaces. However, collisions do take place (they are proportional to the density of the surrounding gas environment), and, therefore, the instrument can be hit by molecules deflected during collisions with particles of the surrounding gas. It is quite simple to protect the instrument from molecules of direct action, but it is impossible to protect it from molecules of back action which appear as a result of collisions. Therefore, it is necessary to concern ourselves with a calculation of the number of collisions capable of returning the molecules to the measuring device.

The number of molecules of direct action crossing the inner limits of the envelope d per unit of time will conform to equation (5) and have the appearance

$$N'_x = N_0 e^{-\frac{x}{\lambda^*}} \tag{8}$$

Because of outward collisions from envelope d, a molecule will emerge:

$$N''_x = N'_x e^{-\frac{a}{\lambda^*}}$$

By taking equation (8) into consideration and assuming that d = 1 cm, we will receive

$$N''_x = N_0 e^{-\frac{x}{\lambda^*}} e^{-\frac{1}{\lambda^*}} \tag{9}$$

The difference between equations (8) and (9) gives the total number of molecules which were subjected to collisions within the envelope and were, as a result of this, transformed into the molecules of back action

$$N^* = N_0 e^{-\frac{x}{\lambda^*}} \frac{1}{\lambda^*}$$

By taking advantage of the correlation which is analogous to equation (6) together with the obtained values for N^*, and with the consideration that the velocity of the returning molecules v_m' will differ from the velocity of the molecules of direct action v_m, it is easy to calculate the number of molecules of back action which are created per unit of volume in distance x from the satellite. However, contrary to the case of molecules of direct action, wherein a corresponding concentration is determined by "one" source of molecules, namely, the surface of the satellite, the concentration of molecules of back action will be determined by the space source, since these molecules are born wherever molecules of direct action penetrate. Therefore, in order to obtain a full concentration of deflected molecules for a certain distance a from the surface of the satellite, it is necessary to summarize all returning molecules which originate within a column of an individual section extending from a to infinity. (Measurements conducted with a satellite are endangered only by those molecules of back action which are created in front of it in a column with radius R, the longitudinal axis of which coincides with the axis of the satellite's motion. At the same time, we neglect the effect of dispersion and consider that all molecules which were created in the indicated column of air are impinging on the satellite and are "destroyed." Obviously, such an assumption will not lead to any great errors, since the loss of molecules through the sight surface of the column will be compensated for by a similar increase of molecules from the outside.) In this manner, the concentration of molecules of back action β_a on the level a will be

$$\beta_a = \frac{N_0}{4\pi v'_m \lambda*} \int_a^{\infty} \frac{e^{-\frac{x}{\lambda*}}}{(R+x)^2}\, dx \tag{10}$$

Insofar as the absolute volume is concerned, in the system of coordinates characteristic of the satellite, the velocity of molecules of back action v'_m considerably surpasses the velocity of the molecules of direct action created by them. Therefore, we may assume that

$$\left| v'_m \right| = n \left| v_m \right|$$

where $n > 1$.

If the measuring device is located near the surface, then the integration should be conducted from 0 to infinity:

$$\int_0^{\infty} \frac{e^{-\frac{x}{\lambda*}}}{(R+x)^2}\, dx = \frac{1}{R} + \frac{e^{\frac{R}{\lambda*}}}{\lambda*} \mathrm{Ei}\left(- \frac{R}{\lambda*}\right) \tag{11}$$

For altitudes of 200 km and more, where $\lambda^* > R$, we may disregard the second item of equation (11). In this case, equation (10) will have the following form:

$$\beta_0 = \frac{N_0}{4\pi n v_m \lambda^*} \frac{1}{R} \tag{12}$$

The number of molecules of direct action near the surface of the satellite conforming with equation (7) will equal

$$\rho_0 = \frac{N_0}{4\pi v_m} \frac{1}{R^2} \tag{13}$$

By securing the relation of equation (12) and (13), we will obtain

$$\frac{\beta_0}{\rho_0} = \frac{v_m R}{v_m \lambda^*} \tag{14}$$

The relation of equation (14) indicates that the number of molecules of back action depend on the radius of the satellite and the relation of velocities and escape. Other things being equal, a satellite with a smaller radius should yield a smaller percentage of returning molecules.

Table 1 represents the variation in the relationship of β_0/ρ_0 with altitude (for R = 100 cm, and n = 10). On the basis of the data from Table 1, it is possible to make the following conclusions:

> When determining the density or chemical composition of the surrounding gas, the distorting influence of molecules of

back action at altitudes above 200 km may be disregarded as compared with the influence of molecules of direct action. Measurements made by the satellite will be dependable until the concentration of molecules of back actions occurring near the surface of the satellite becomes commensurable with the concentration of particles from the free atmosphere at the given altitude. It should be mentioned that by the given constant of concentration ρ_0, the relationship ρ_0/ρ_{atm} is the constant value for all altitudes (ρ_{atm} is the concentration of molecules in the free undisturbed atmosphere).

2. Below 150 km a different picture can be observed: a noticeable number of evaporating molecules collide with each other in the immediate vicinity of the surface and may again return to the satellite.

C. Some Numerical Calculations

For appropriate calculations, it is necessary to adopt some intelligent assumptions concerning the number of molecules N which were carried by the satellite into the upper layers of the atmosphere. In addition, it is necessary to deal with the evaporation period T of these molecules which emanate from the surface of the satellite. Assuming that 1 cm^2 may carry 10^{15} molecules and that the absorption is polymolecular and equal to, let us say, 50 layers, whereby the over-all surface of the satellite is 10^6 cm^2, we will obtain the over-all number of sorbent molecules:

$$N = 10^{15} \times 10^6 \times 50 = 5 \times 10^{22}$$

We will limit the desorption period T to one revolution of the satellite around the Earth, which equals about 5,000 sec. We will consider that the absorption takes place uniformly. Actually, this is not the case. However, the made assumption rather strengthens the effects connected with gas discharge and does not weaken them.

$$N_0 = \frac{N}{T} = 10^9 \text{ mole/sec}$$

For the solution of equation (7) we have, in addition, $R = 10^2$ cm, $v_m = 4 \times 10^4$ cm/sec, $v_c = 8 \times 10^5$ cm/sec, and $k = 5 \times 10^{-2}$.

The evaporating molecules of direct action create a peculiar "halo" around the satellite. The illustrated graph (Fig. 1) shows the density variation of this halo as a function of the distance from the surface of the satellite and the altitude of its flight. (As an example, three altitudes were considered: 100, 150, and 300 km.) It is obvious from this graph that with the increase in flight altitude, the density of the halo or cloud drops more slowly during its escape from the surface of the satellite. Therefore, at an altitude of 300 km, the concentration of the evaporating molecules remains extremely high and practically unchangeable within the metric layer of space which surrounds the satellite. On lower altitudes, this layer decreases considerably.

The illustrated graph permits making some recommendations in regard to the distribution of measuring equipment in the satellite. There is no point in placing instruments at a distance of less than 2-3 meters from the surface of the satellite if the satellite is to attain an altitude of 250 km or more. As we have previously indicated, the correct orientation of the instrument should be guided by the efforts to protect it from the evaporating molecules and be oriented with the entrance opening pointing to the outside.

Entirely different is the situation with the always dangerous back action molecules. In order to decrease their harmful influence, it is extremely important to place the measuring instrument far away from the surface of the satellite. According to equation (10), each 10 cm which separates the surface of the satellite from the inlet opening of the instrument (the distance a in equation (10)) shows a noticeable drop in the concentration of deflected molecules, since the entire region between the satellite surface and the instrument--the region which contains the most deflected molecules--is excluded from the sphere of measurement. For an ideal case, the instruments should be moved from the surface by a distance approximately equal to the radius of the satellite R. In this case, the entire basic mass of deflected molecules will be formed "behind" the instrument and will be "destroyed" on the surface of the satellite without causing any more harm to the conducted measurements.

Simultaneously, with the calculation of gas discharges from the surface of the satellite, calculations can be made in a similar manner of the tolerable fluxes (gas losses from within the satellite), which also allow measurements of the undisturbed parameters of the atmosphere. Assuming that all fluxes exerted on a satellite are concentrated on 1 m^2 of its surface and the instruments are located at the center of this surface, the permissible fluxes would, in accordance with equation (7), measure about 10^{19} molecules/sec. As was indicated above, the value of permissible fluxes at a constant gas discharge will be constant for all altitudes. The indicated value of fluxes is permissible only in that case when the instrument is not hit by molecules of direct action. If the instrument is not protected against such molecules, the errors of density measurements may be very considerable and will increase proportionally to the density decrease of the surrounding environment. Thus, by taking the indicated precautions, the gas discharge from the satellite will cause no noticeable changes in the measurements of the density and the nature of the surrounding gas, even in the presence of considerable and constant leaks.

D. The Influence of Molecules on the Surrounding Environment

According to the law of deflective collisions, the surrounding gas environment is most actively affected by molecules which collide with the satellite and are deflected from its surface. These molecules, having a velocity of 15--16 km/sec and an energy of about 30 ev, might easily cause ionization as well as effect other changes in molecules which they encounter. In order to calculate the concentration of rapid molecules, which are deflected to a distance x from the surface of the satellite, one may apply equation (7), considering that the surface emits rapid molecules, the number of which varies proportionally to the variation and density of the surrounding environment. During an appropriate calculation in formula (7) the numerical value of the coefficients N_0, V_m, and k should be changed. Should one investigate the altitude at 200 km, where the concentration of gas $\nu = 10^{10}$ mole/cm^3, then, during a period of 1 sec, a satellite with a cross section of 3 m^2 will bring into motion $N_0 = 10^{10} \times 10^5 \times 8 \times 3 \times 10^4 = 2.4 \times 10^{20}$ mole/sec. (In this case, $v_m = 8 \times 10^5$; $K = 1/\sqrt{2 \approx 1}$.) By substituting the indicated values in equation (7) and doubling this value (in this case, the molecules expand only along the forward hemisphere), we will obtain an additional concentration created by deflected molecules, which, at an altitude of 200 km, will amount to $2 \div 3 \times 10^9$ mole/cm^3 near the satellite's surface.

This concentration will drop with the increase in altitude. However, the relation of the concentration of deflective molecules to the concentration of molecules of the undisturbed atmosphere should remain constant. Consequently, the change in density of the surrounding space due to the rapid (deflective) molecules of direct action is even more insignificant than in the case of slow (evaporated) molecules.

If the molecule which has deflected from the satellite possesses a velocity of $v_m = v_c = 8$ km/sec, then $k = 1$ and $\lambda^* = \lambda_{sr}$ (considering that after a nondeflective collision of a rapid molecule with a molecule of the environment, it loses a considerable part of its velocity). For an altitude of 200 km, where $\lambda_{sr} = 10^4$ cm and $n \approx 1$, we will have, according to equation (14), $\beta_0/\rho_0 - 10^{-3}$; that is, a concentration of back action particles near the surface of the satellite is $\beta_0 = 2 \times 10^6$ mole/cm^3.

With the increase in altitude, this concentration will drop more rapdily than the concentration of the surrounding environment.

We should evaluate the danger of these collisions to the measurements conducted by the satellite on the ionization, content, and density of the undisturbed atmosphere. If we assume, with Herlofson (Ref. 2), that the coefficient of ionization during similar collisions is $\alpha = 10^{-4}$, we will find that nearly a hundred additional ions may be created within 1 cm^3 near the surface of the satellite, which is negligible in comparison with the natural ionization (10^5 - 10^6 ion/cm^3). Even if we assume that the section of these processes is proximate to a unit, the occurrence of a thermochemical reaction is also very unlikely. Consequently, it is impossible to anticipate any noticeable changes in the composition of the surrounding atmosphere because of the collisions which take place. Finally, even at an altitude of 200 km, the change in density of the surrounding space due to deflective molecules will be insignificantly small (2×10^6 mole/cm^3 at 10^{10} mole/cm^3 being present in the atmosphere).

E. Conclusions

Within the limits of the hypotheses, the discussion on the question of the influence of disturbances caused by the satellite in the upper layers of the atmosphere indicates that,these perturbances cannot noticeably change the results of the conducted measurements on density determination, ion contents, and concentration of positive or negative ions.

We think that the results of two experiments conducted with the satellite can serve as a confirmation of these assumptions: the experiment to determine the density (Ref. 3) and the experiment to determine the chemical composition of the ionosphere (Ref. 4). In the first case, a small, excessive concentration of molecules occurring during the period of the first revolution of the satellite can be explained (1) by a certain possibility of a collision between a molecule of direct action with the measuring instruments, and (2) by the large amount of absorbed water which was distinctly registered by the mass spectrometer (Ref. 4).

Furthermore, the absence of ions of absorbed molecules of nitrogen and oxygen in the mass spectrum of a mass spectrometer testifies to the fact that the ionization of the molecular bombardment is extremely insignificant.

The presence of ions of water in the mass spectrum of the instrument (Ref. 4) is quite conspicuous. The results of preliminary processing of the obtained data do not leave any doubts that the water is created by the satellite itself (desorption from the surface). The difficulty seems to be confined to the clarification of its ionization, since the presence of ions of water cannot be explained by the mechanism of collision (water is registered also in the region of molecular umbra where there are no collisions) or by the mechanism of photoionization (a negligible potential).

This interesting phenomenon should be explained either by the presence of an additional ionization agent in the upper layers or by some processes which take place on the surface of the satellite. (Additional ionization in the upper layers of the atmosphere is confirmed by the recently discovered, quite intensive radiation, Refs. 5--7, the study of which is being continued at the present time. It should be mentioned that the effect and density of the new radiation should be very large.)

In conclusion, I would like to express my gratitude to the Doctor of Physical and Mathematical Sciences, B. Y. Levin.

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Table 1

H, km	λ_{sr}, cm	λ^*, cm	β_0/ρ_0
500	10^6	5×10^4	2×10^{-4}
300	10^5	5×10^3	2×10^{-3}
200	10^4	5×10^2	2×10^{-2}
150	2×10^2	10^2	10^{-1}

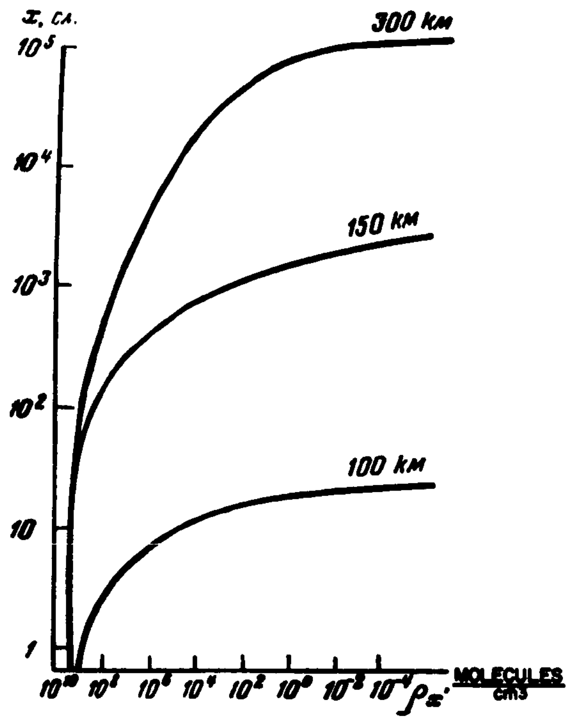

Fig. 1. Change in Density of Molecule "Cloud" as a Function of Distance from the Earth's Surface

4. PRELIMINARY RESULTS IN DETERMINING THE ATMOSPHERIC DENSITY ABOVE 100 KM

V. V. Michnevich

The study of the structural parameters of the atmosphere using rockets and satellites occupies a prominent place in the IGY program. In the U.S.S.R., these investigations are conducted up to an altitude of 80 km with the help of meteorological rockets, and to higher altitudes by means of geophysical rockets and satellites.

For the measurement of pressure and density of the atmosphere, various types of manometers are used which permit the measurement of pressure from the atmospheric level and up to 10^{-9} mm Hg. Pressure measurements between the limits of 10^{-5} to 10^{-7} and 10^{-5} to 10^{-9} mm Hg are conducted by special magnetometers and thermoionization manometers, respectively.

It is impossible to utilize the ordinary ionization manometers for the measurement of pressure within specified limits in an ionized environment since the currents formed in the manometer by ions and electrons present in the free atmosphere are comparable to the currents of manometers, which are a measure of pressure. Therefore, in the ionization manometers which are used for the measurements of pressure and ionization of the environment, a separation of these currents is accomplished with special screens and traps, and only these currents are measured which happen to be the standard for pressure.

In Figs. 1 and 2, the above-mentioned thermoionization and magnetic manometers are schematically reproduced. In order to decrease the photo current from the collector into the thermoionization manometer, the collector is made in the form of a thin wire (Figs. 1 and 2). With the help of an additional screen placed between the cathode and the anode (Figs. 1 and 4) the self-stabilization of the emission current is established.

The manometer current is amplified by a dc amplifier and fed to the telemetry input. A block diagram of this instrument is shown in Fig. 3. The manometer is launched into the upper layers of the atmosphere in an evacuated state and is uncovered at a specified altitude. During the entire flight period, the ion flux of the manometer is continuously registered; periodical calibrations of the amplifier and the manometer emission currents and also the temperature of the manometer walls are measured.

The measurement of pressure and density of the atmosphere at high altitudes is an extremely complicated problem and, until the completion of the experiment, even debatable.

During the measurements of low pressures, such as 10^{-6} to 10^{-9} mm Hg, a series of problems arose:

1. What is the photoemission of the manometer electrodes which is caused by short-wave solar radiation?
2. Will it be possible to conduct correct measurements of the gas discharge pressure of the surfaces of rockets and satellites?
3. How should the manometer be placed?
4. Is it possible to measure the pressure in an ionized environment with ionization manometers?

5. What is the composition of gas and temperature in the upper layers of the atmosphere, and how can a probable change of composition and temperature affect the readings of the manometer?

6. What is the dynamic effect?

Atmospheric pressure and density for periods of free runs of molecular gas, in the case of large-dimension manometric inlet openings, are a complicated function of pressure or density measured with a manometer, of angle of attack, and of velocity of the object on which measurements of composition and temperature of gas in the atmosphere and in the manometer are being made. In the case of large velocities of the object (in comparison with the molecular velocity of gas in the atmosphere) and in the case of large attack angles it is not necessary to know the temperature of the environment in order to determine the atmospheric density.

In 1957 (Ref. 1) possible errors in the determination of pressure and density of the atmosphere were investigated with the help of manometers placed on a satellite. We will concern ourselves only with these cases which were not described in detail in the above-mentioned work.

A. Gas Discharge

It was shown by the works of Soviet investigators (Ref. 2) that with the execution of proper hermetization (gas escape from rockets or satellites should not exceed 1 cm^3/sec at atmospheric pressure) and the choice of construction materials which have a low vapor tension, the gas discharge by a rocket or satellite has practically no effect on the pressure or density measurements of the atmosphere if the barometer is protected from direct contact with the escaping gas.

During the construction of a satellite, very extensive work is done on the determination of vapor tension of various construction materials at temperatures from 20--300°C and likewise of the degassing period of various materials which had remained under atmospheric pressure for a long period of time. For the construction of a satellite, only such materials were used which satisfied the requirements specified above.

B. Change of Air Composition

Above 100 km the atmospheric composition changes with the altitude as a result of disassociation and defusing separation. At the present there are no precise data available on the level of diffusing separation and the character of disassociation of oxygen and nitrogen with altitude.

It seems to us that the level of diffusing separation is not stable and depends on the thermodynamic state of the atmosphere. This was indicated by the investigations of the determination of the level of diffusing separation which was carried out by the Naval Research Laboratory of the United States of America with the help of high-frequency mass spectrometers of the Bennett type (Refs. 3 and 4). Thus, data pertaining to the launching of the NRL-13 Aerobee on February 12, 1953, in New Mexico, disclose the absence of diffusing separation at least up to an altitude of 137 km. The results of investigations of the NRL-18 Aerobee-Hi at Fort Churchill, November 20, 1956, make it possible to ascertain that, within the region of 112 - 150 km, a diffusing separation of argon and nitrogen is taking place.

Even though it can be considered as established that the disassociation of oxygen begins above 90 km, it is not precisely known at what altitude molecular oxygen disperses. The quantitative distribution of atomic and molecular nitrogen in relation to altitude is also presumable. What, then, is the error which occurs because of the change of air composition when the atmospheric density and pressure above 200 km are determined with the help of manometers, the graduation of which was made under ordinary air conditions?

For the evaluation of this error, we availed ourselves of a sample of atmosphere as suggested by Miller (Ref. 5). At an altitude of 200 and 500 km, the magnitude of the error is on the order of 20 and 60%, respectively.

A preliminary analysis of all errors, including the errors obtained in determining altitude, velocity, calibration, and telemetry, and also in the basic assumptions during the interpretation, yields a maximum error during the determination of density in excess of 200 km at separate points, amounting to about 200%. Further processing of measurement results together with the consideration of data obtained from rockets and satellites and including also data on the atmospheric composition of these altitudes will make it possible to decrease these errors.

C. Results

In February of 1958, a geophysical rocket equipped with manometers was launched during the daytime, and density measurements of the atmosphere were carried out to altitudes of 260 km.

Concurring with other rocket experiments (Ref. 8), the results of which are given in this paper, the launching of this rocket took place in the middle latitudes of the European part of the USSR.

One magnetic and two thermoionization manometers were installed aboard the third Soviet Satellite, which was launched on May 15, 1958. When the satellite entered its orbit, a special mechanism uncovered the manometers and switched on the measuring instruments. In compliance with the program, measurements were conducted over a period of one week. Pressure and density at various latitudes, longitudes, and altitudes were measured during this period.

Since the processing of measurement results is very complicated and difficult, we have at our disposal at the present time only some results from several points along the satellite's fifteenth orbital revolution.

Figure 4 and Tables 1 and 2 show the results of density measurements made with rockets and some preliminary data on atmospheric density obtained with the satellites (curve 6, in the region 10^{-13} to 10^{-14} is added by approximation). For comparison, we feature in the graph the standard atmosphere of the USA for 1956 (Reg. 6), the results of measurements conducted with the Viking 7 (Ref. 7), and data on density obtained during satellite deceleration (Ref. 9).

The calculation of atmospheric density by pressure as measured inside the manometer was conducted according to the formula

$$N = P_1 \sqrt{\frac{1}{2\pi mK} \times \frac{1}{T_1 v \sin \theta}} \qquad (1)$$

where P_1 is the pressure inside the manometer, T_1 is the temperature of gas inside the manometer, v is the velocity of the satellite or rocket, θ is the angle between the vector of velocity and the plane of the manometer opening, k is the Bolzmann constant, and m is the mass of the molecule (adopted from Ref. 5).

An examination of the measurement results points to an increase in height of the homogenous atmosphere as a function of altitude.

As is obvious from the illustrated formula, the volume of pressure inside the manometer depends on the orientation of the satellite. Figure 5 shows the comparable character of the change of pressure in the manometer, depending on altitude and orientation of the satellite. The time of measurement is indicated on the abscissa axis and the inside pressure of the manometer on the ordinate axis.

The antennas, ion traps, etc., were located on the satellite in such a manner as to allow the gas escaping from them to strike the manometer opening directly (the manometer "saw" the antenna, trap, etc.). Therefore, the minimum pressure which was recorded by the manometer varied with time. The first day, during the first revolution, the volume of minimum pressure was about 1×10^{-7} mm Hg. The second day it was 1×10^{-8} mm Hg; the third day, 1×10^{-9} mm Hg.

A large number of scientists have taken part in the determination of atmospheric density above 100 km using rockets and satellites; their work has included the creation of instruments, the theoretical interpretation of obtained data, and the preparation and conduct of experiments. The greatest contributions were made by the following: E. N. Goshchitskava, A. M. Grigorev, B. S. Danilin, E. V. Meizerov, A. I. Repnev, V. A. Sokolov, L. P. Khavkin, and E. G. Shvidkovshy.

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Table 1. Atmospheric Density as Determined by Containers (Ref. 8) and Rockets

Height, km	Density, g/cm^3	Height, km	Density, g/cm^3
60	3.9×10^{-7}	170	6.4×10^{-13}
70	1.36×10^{-7}	180	4.4×10^{-13}
80	2.9×10^{-8}	190	3.3×10^{-13}
90	3.3×10^{-9}	200	2.7×10^{-13}
100	4.10^{-10}	210	2.3^{-13}
110	9.8×10^{-11}	220	1.6×10^{-13}
120	2.2×10^{-11}	230	1.25×10^{-13}
130	7.4×10^{-12}	240	1.1×10^{-13}
140	3.2×10^{-12}	250	9.10^{-14}
150	1.6×10^{-12}	260	6.9×10^{-14}
160	9.5×10^{-13}		

Table 2. Comparison of Measurement Results of Atmospheric Density Obtained by Various Methods and Authors

Altitude, km	Density, g/cm^3		Altitude, km	Density, g/cm^3	
	USSR Containers and Geophysical Rockets	USA Viking-7		Rockets USSR	Satellite
100	$4 \cdot 10^{-10}$	2.5×10^{-10}	228	1.3×10^{-13}	$2.4\text{-}3 \times 10^{-13}$ (based on drag, USSR)
150	1.7×10^{-12}	6.6×10^{-13}	260	6.9×10^{-14}	$1 \cdot 10^{-13}$ (based on manometers, USSR)
200	2.7×10^{-13}	1.4×10^{-13}	355		8.8×10^{-15} (based on manometers, USSR)
220	1.6×10^{-13}	9.0×10^{-14}	368		1.4×10^{-15} (based on drag, USA)

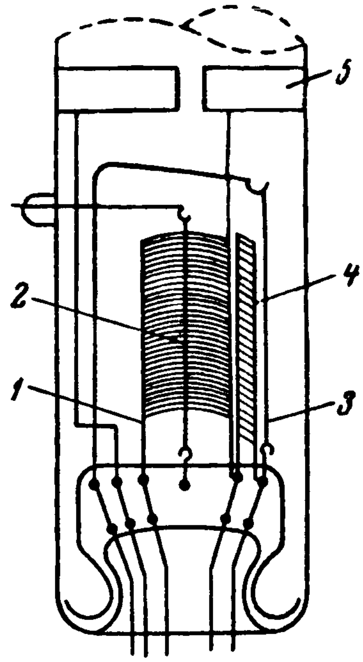


Fig. 1. Heat Ionization Manometer
(1- Accelerating grid-anode; 2- Collector; 3- cathode filament; 4- emission stabilizator grid; 5- trap)

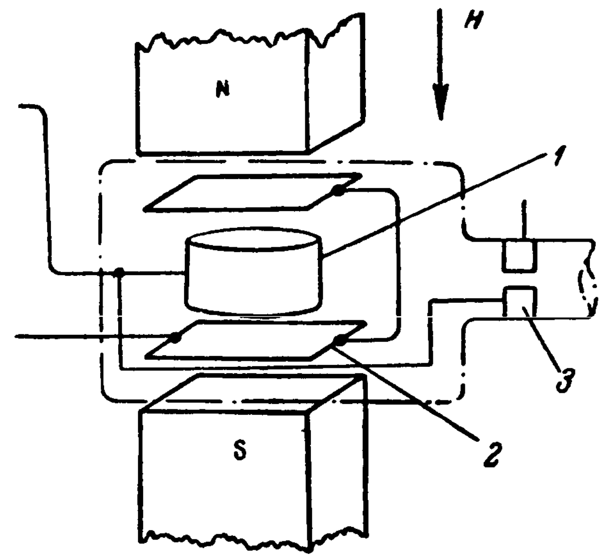


Fig. 2. Magnetic Ionization Manometer
(1- frame-anode; 2- plates-cathode; 3- trap)

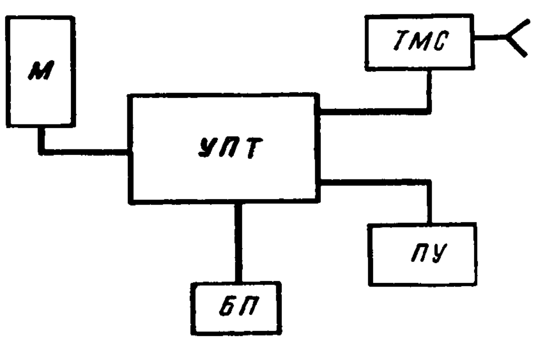


Fig. 3. Block Diagram
(M-manometer; UPT - DC amplifier; PB-power supply block)

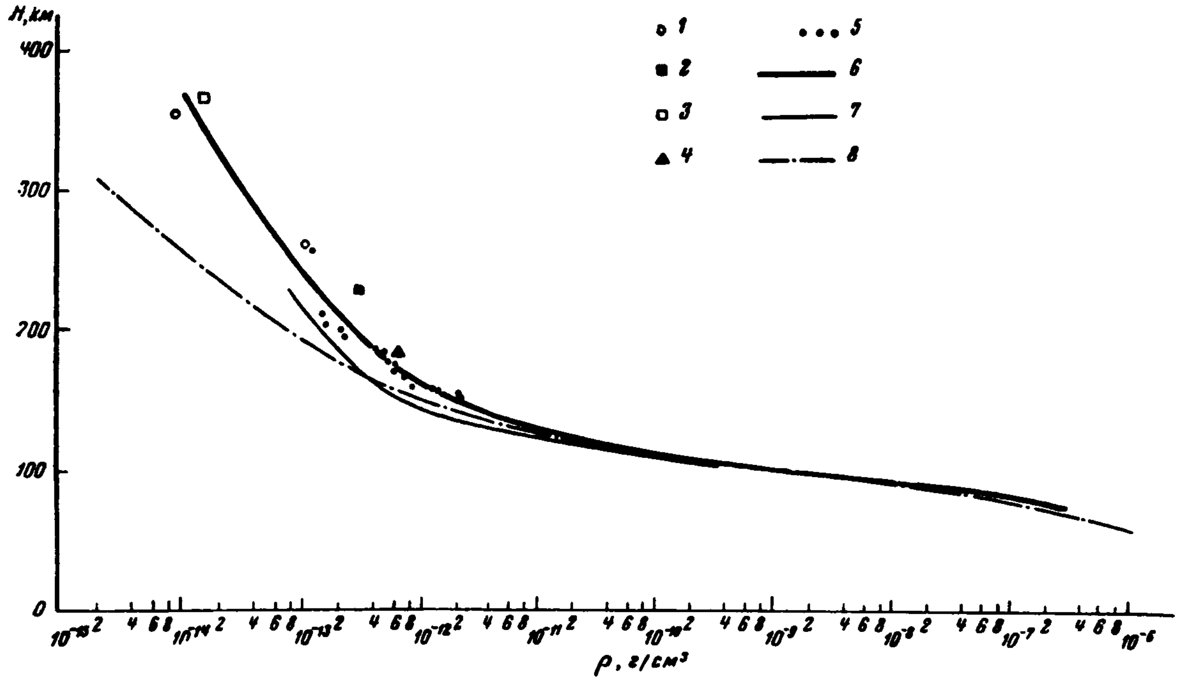
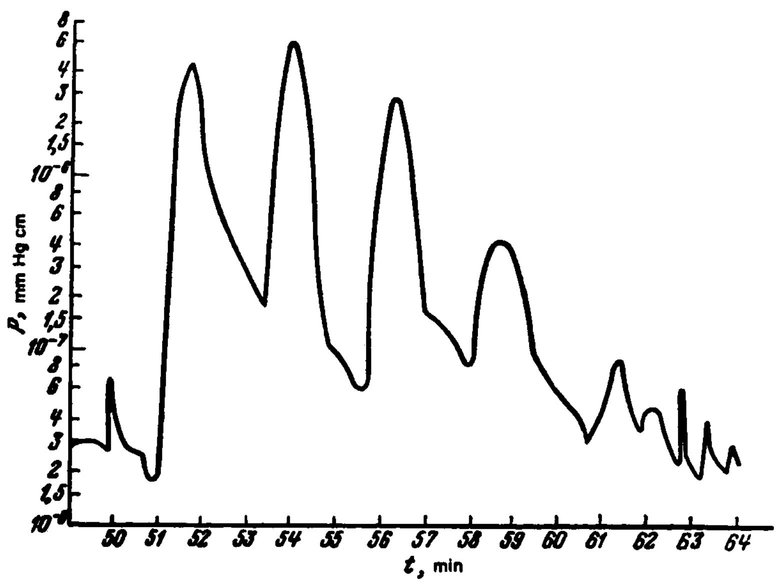


Fig. 4. Atmospheric Density According to Rocket and Satellite Measurements

Fig. 5. Pressure Change Inside the Manometer in Relation to Altitude and Satellite Orientation (Example)



5. INVESTIGATION OF THE ION COMPOSITION OF THE EARTH'S ATMOSPHERE WITH ROCKETS AND SATELLITES

V. G. Istomin

Investigation of the ion composition of the Earth's atmosphere began in the Soviet Union in 1957. Work on the construction of suitable instrumentation has been conducted since 1955.

A. The Method of Measurements

A 705-cycle version of the Bennett-type radio frequency mass spectrometer is used at present for investigation of the ion composition of the Earth's atmosphere. The spectrum of positive ion masses within the range from 6 to 50 atomic mass units (amu) is being investigated.

The schematic of this device and the principle of operation are sufficiently well known (Ref. 1). Therefore, we will concern ourselves only with some specific features of this instrument and its method of application.

The basic characteristics of this instrument are as follows: range of mass is 6-50 amu; period of measurement in the range is 1.7 sec; resolution in the region of the mass number $M = 28$ is equal to $R = M/\Delta M \approx 28$, where ΔM is the width of the peak as measured at its base in amu. The input resistance of the dc amplifier is 10^{10} ohm. The amplifier has two outputs: one of high and the other of low sensitivity, with voltage amplification coefficients of about 0.8 and 0.05, respectively. The amplifier characteristic is linear up to an input intensity of about 110 volts.

The mass spectrometer tube of the instrument is of demountable metal and glass construction. The all-metal radio frequency analyzer is coupled with an ion source by means of a vacuum shield and a copper gasket. The flask of the analyzer is made of stainless steel. Single row grids made by winding tungsten wire around kovar rings are used in the radio frequency analyzer and ion source. The grid threads are welded to the ring. The thickness of the grid threads is 18 microns, and the winding interval is 0.5 mm. The operating diameter of the grid is 30 mm. The use of single row grids simplifies and reduces the cost of design of the mass spectrometer tube without decreasing the operating quality of the instrument. In particular, the resolution of the tube with a single row grid is somewhat higher than in a similar tube using a net grid (Ref. 2).

The mass spectrometer tube with a coupled ion source is degassed by being heated to 400°C; it is then filled with a mixture of argon and neon under a pressure of around 3×10^{-5} mm Hg and separated from the vacuum apparatus. After this, the gas absorber is dispersed within the tube. In such a manner, the tube can last for a long time and retain its operating abilities without requiring the vacuum apparatus for its evacuation.

It is more convenient and of greater advantage to work with a sealed tube filled with a mixture of known inert gases. Above all, it is possible, at any stage of the preparation of the experiment, to record the known mass spectra with the help of a radio-telemetry system and thus obtain a record by which it will be possible to construct a calibration characteristic according to masses along the entire link between the mass spectrometer and radio-telemetry system.

This makes it possible to avoid all intermediate stages of calibration and consequently increases the accuracy for determining mass numbers. The calibration characteristic is established according to five datum points on the mass-scale: A^{40}, A^{36}, N_2^{28}, Ne^{22}, Ne^{20}. The presence of the stable filler in the mass spectrometer tube makes it possible to tune the instrument quickly, establishing the desired operating regime (resolution) according to the neon peaks Ne^{20} and Ne^{22}. In order to obtain comparable results, all instruments are tuned uniformly up to the value of resolution R = 20 according to the peak in the region of masses 20--22 (at the peaks of neon Ne^{20} and Ne^{22}). Finally, by using the tube with the filler, it is always possible to check fully the operation of the instrument and ascertain that its adjustment and operating regime have not changed.

The unsealing of the tube (disconnection of the ion source) took place immediately before its installation in the rocket or satellite.

With the help of the radio-telemetry system, the voltage at the output of the dc amplifier, the sawtooth-like voltage of the mass scanning, the retardation potential, and a series of other controlling parameters were registered.

Decoding of the peaks on the recording was accomplished by determining the value of the sawtooth voltage, which corresponds to the appearance of the crown of the peak, and by comparison with the calibration characteristic.

B. Results

1. Vertical ascent. The first ascent of a radio frequency mass spectrometer was accomplished in a cylindrical instrument container

which was delivered by a rocket to a high altitude. The purpose of the experiment was to check the instrument under actual operating conditions.

The launching was made on September 9, 1957, after sunset. The descent of the Sun at the moment of launching was 6 deg, which corresponds to the height of the Earth's shadow of about 60 km. Data on ion composition were obtained from an altitude of 105 to 206 km. A total of about 70 spectra recordings was obtained. Ions with two masses (mass number 16 and 30) were registered. Data were obtained on the distribution of these ions relative to altitudes. The results of the experiment show that ions with a mass number 30 predominate at altitudes of 105 to 206 km. Ions with other mass numbers are present at altitudes of 105 to 190 km in quantities which do not exceed 20% of the maximum ion concentration with a mass number of 30.

Figure 1 shows the change with altitude of the mass spectrum of ions which were registered during this flight. The peak amplitude of ionic current on a telemetry recording is projected on the abscissa axis, and the altitude, in km, is projected on the ordinate axis. This graph shows a distinctly registered layer, with its maximum at an altitude of 143 km, formed by ions with a mass number of 30 (presumably nitric oxide, NO^+). Data obtained during the ascent and descent match favorably for altitudes of 105 to 175 km.

Ions with mass number 16 (presumably atomic oxygen) were recorded only during the ascent from 192 to 206 km. No discovery was made during the experiment of any kind of systematic shifting of peaks on the mass scale which could be attributed to the influence of the container charge. On the basis of an analysis of the experimental results it can be stated that during the experiment the potential of the container remained constant within the limits of ±2 volts. (This follows from the fact that the shifting of peaks on the voltage scale which exceeds ±0.5% would have been discovered during processing. The displacement of ±0.5% corresponds to a drop of the peak on the mass scale by ±0.34 amu, or, if we consider the value of the constant of the instrument to be 6.5 volts/amu, it will correspond to a shift of ±1.9 volts on the voltage scale. At the same time the whole-number value obtained of mass numbers indicates that the potential of the container equaled 0 ± 2 volts, since it is difficult to expect potential values on the order of 6.5 ± 2 volts.)

2. Mass spectrometer investigation with Sputnik III. A radio-frequency mass spectrometer was installed on Sputnik III. During the operation of the instrument, several thousand mass spectra of positive ions of a large altitude range were obtained. It was, of course, impossible to include in this report an exhaustive analysis of the obtained results, since even the initial processing of the material is far from being completed.

Preliminary processing results of data from some of the first spirals of the satellite can be reduced to the following. At altitudes from 250 km on the basic (predominating) components are ions with a mass number of 16, which are ions of atomic oxygen O^+. These ions were registered at altitudes of 230--885 km. Ions with a mass number 14, which are ions of atomic nitrogen N^+, form the second component of the ionosphere. The ion current with a mass of 14 constitutes 3--8% of an ion current with a mass of 16, with a tendency towards an increase of this percentage with altitude. The corresponding dependence (based on data from two spirals) is shown in Table 1. The operating regime of the instrument along the first spiral differed from a normal one because the satellite had a negative potential of about -5 volts. Data on the satellite potential were obtained from an experiment during which the concentration of positive ions was measured (Ref. 3). These data are confirmed by the presence of harmonic peaks in the mass spectra. The level of the lower harmony of mass-number 16 is about 0.10 - 0.12.

The maximum current value at the collector of the mass spectrometer tube as registered on the first spiral is 200×10^{-10}a (at 250 km altitude). The minimum recorded current has a magnitude of about 0.1×10^{-10}a. The maximum altitude on which mass spectra were obtained is 885 km. At this altitude the ion current with a mass of 16 is 1.3×10^{-10}a.

Besides the peaks, which correspond to the ions O^+ and N^+ in the spectra obtained during the first spiral, there are peaks present which, according to the character of their intensity, may eventually be attributed to contamination.

The maximum ion current with a mass of 18 is 3×10^{-10}a. Ions with a mass of 18 (besides the first spiral) were recorded on the third spiral, wherein the current was about 0.5×10^{-10}a. Ions with a mass number of 18 were not observed in further spectra.

Concluding, the author expresses his gratitude to E. A. Mirtov, director of the laboratory, for his constant interest in this work and for his help in evaluating the experimental results, and also to the co-workers of the laboratory: the junior scientist R. P. Shirshov,

senior engineer L. T. Chulkin, technical constructor O. V. Rodionov, and the laboratory technicians, A. A. Perno and S. V. Vasyukov, who have done a great job on the construction and testing of the equipment.

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   Mirtov, B. A., Istomin, V. G., UFN, 63, edition 1b, 227, 1957.
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Table 1

Altitude, km	230	250	255	285	385	460	650	750
i_{N^+}/i_{O^+}	0.037	0.03	0.035	0.045	0.06	0.06	0.07	0.06

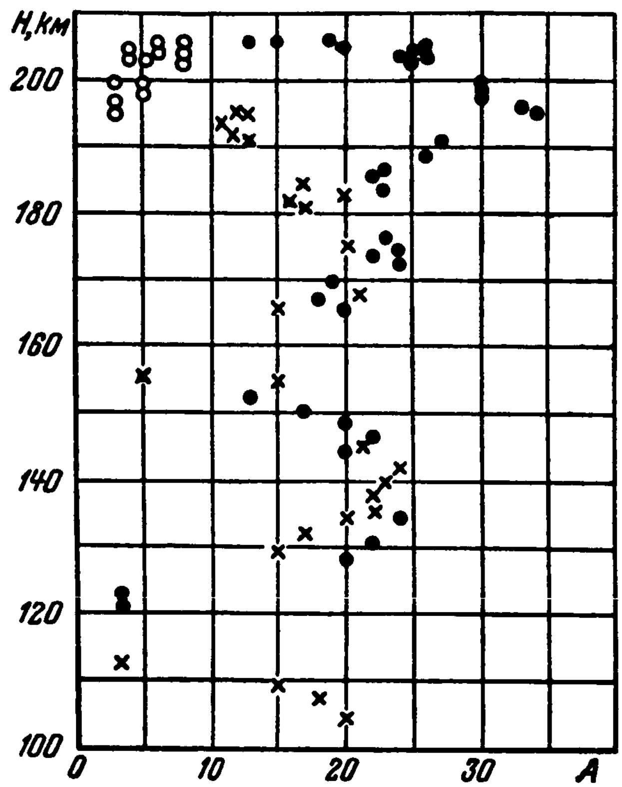

Fig. 1. Change with Altitude of the Number of Ions Which Were Registered by the Mass-Spectrometer During the Launching of the Rocket on September 9, 1957. (On the Abscissa axis is shown the amplitude of peak A as recorded in corresponding units; on the axis of the ordinate is shown the altitude H in km above the surface of the Earth. Ion measurements with a mass number of 30 (MO) during ascent are indicated by points; during descent they are indicated by crosses. Ion measurements with a mass number of 16 (O) during ascent are indicated by circles.

6. SOVIET INVESTIGATIONS OF THE IONOSPHERE WITH THE HELP OF ROCKETS AND SATELLITES

V. E. Krasovsky

The methods for investigation of the ionosphere may be divided into four groups.

1. The investigation with the help of radio waves refracted from the ionosphere by surface radio transmitters.
2. The investigation of radio emission which passed through the ionosphere from sources lying beyond the Earth (the Sun and radio sources) and the investigation of emission from ground sources using the Moon for radio location.
3. The investigation of radio emission from sources which travel through the ionosphere with the help of rockets and artificial Earth satellites.
4. The investigation with the help of devices which directly determine the characteristics of the ionosphere in the vicinity of rockets or satellites (Langmuir-probe technique, ion traps, mass spectrometers, etc.), data of which are transmitted to Earth by means of radio-telemetry.

Until recently, basic information on the ionosphere was obtained by investigating the radio waves with the help of ground equipment. Only the method of inpulse-radio probing of the ionosphere was widely used. However, the study of signals reflected from the ionosphere could not basically solve the problems of distribution of the electron concentration along the entire vertical section of the atmosphere, since it is impossible, with this method, to perform an exhaustive investigation of the wide layer of ionosphere in which the ionization density decreases with respect to altitude, or does not exceed the ionization density in the lower regions. Indeed, if the analysis of a group delay of radio-wave impulses of various frequencies which are reflected from the F region allows certain conclusions on the electron concentration above the maximum ionization of the E region, it follows that the region which is located above the maximum of the highest (observed with the help of reflected radio waves) could not be investigated by the before-mentioned method.

Through an investigation of the ionosphere by means of radio emission from sources beyond the Earth which pass through the entire thickness of the atmosphere, the integral content of the electrons in its entire vertical column can be determined. By comparing these data with the observations of ionospheric stations, some conclusions can be made concerning electron concentration of the ionosphere's regions above the maximum of its layers. However, this method does not permit one to obtain detailed data on the original distribution of electron concentration according to altitude.

Thus, with instruments located on the Earth's surface, it is impossible to obtain exhaustive data on the distribution of electron concentration throughout the entire vertical section of the atmosphere. This problem might be solved by means of radio methods only under the condition that the sources of emission of radio waves of frequencies exceeding the critical frequencies of the ionospheric layer will drift vertically through the altitude within the ionosphere itself. Here it is of great importance that the vertical shifting of the radiation surface should significantly exceed the horizontal shifting. This condition prevails during the vertical launching of high-altitude rockets. Rockets and satellites offer great possibilities for the investigation of ion and electron concentrations by utilizing direct measurements.

The United States of America published in recent years a series of materials dealing with the measurements of electron concentration in the ionosphere with the help of rockets (Refs. 1-7). The majority of these papers (Refs. 1-5, 7) are concerned with regions above 200 km, and only one of them deals with an altitude up to 380 km (Ref. 6).

In the Soviet Union, the exploration of the ionosphere by means of rockets and satellites is considered to be a problem of prime importance. We will concern ourselves first of all with the investigation of the ionosphere, based on the study of radio wave propagation. We consider the most important investigation in this field to be the measurement of electron concentration in the ionosphere by means of a dispersion interferometer. These investigations were conducted since 1954, while the launching of geophysical rockets of the Academy of Sciences of the USSR was under way (Ref. 8). The method of a dispersion interferometer is one of the radio interferential methods for the investigation of radio wave propagation proposed by the academicians L. I. Mandelshtan and N. D. Papaleksi more than twenty years ago. As far back as 1936 this method was applied to the study of ionospheric radiations of the optical traces of radio waves with a length on the order of hundreds of meters (Refs. 9-11), whereby the radio transmitting and receiving parts of the interferometer were located at various points of the Earth's surface.

During the flight of Soviet artificial satellites, mass measurements of the level of signals received from radio waves of the satellite were conducted. The processed results of these measurements have yielded interesting conclusions about the properties and content of the ionosphere.

Y. L. Alpert and others (Ref. 12) have conducted these measurements in order to establish a possible use of the phenomena of "radio dawn" and "radio set" of the satellite in order to obtain data on the structure of the ionosphere. A. N. Kazantsev and others (Ref. 13) have treated the results of the measurements from the standpoint of determination of absorption of radio waves above the maximum of the F_2 layer. We shall discuss each of these works.

As a basis for the determination of the electron concentration, measurements were used of dispersion of radio waves emitted from a rocket by means of a dispersion interferometer. Tests were conducted as follows. Aboard a rocket launched under a small angle to the vertical, transmitters were mounted having coherent ultra-short-wave-range radio waves of two frequencies, one of which was several times higher than the other. This was accomplished by a variable frequency multiplication of the generator, which was stabilized with quartz. During the rocket's flight, radio waves from the above-mentioned transmitters were received at two points on the Earth's surface. The phase-variation as well as the intensity of the received oscillations were recorded continuously. At the same time, measurements of the rocket's coordinates were conducted by means of optical and radio technical methods. Radio probing of the ionosphere with panoramic ionospheric stations located near the launching site was also conducted. In order to increase the phase surface discrimination of receiving devices, subsequent multiplication of frequencies and heterodyning were employed. The registration of phase differences was accomplished in two ways: by a continuous photographing of the characteristic points of the Lissajous figures from the cathode tube of an oscillograph, using the method as described by E. Y. Shchegolev and others (Ref. 14), and by recording the interferential frequency oscillations which are formed after the detection of the sum of both received signals. In the last case the signal of the low frequency was preliminarily multiplied according to frequency as many times as this frequency was smaller than that of the high-frequency signals. A photographic picture of the instrumentation and examples of recording patterns are illustrated in Figs. 1 to 4.

Appendix A gives the final formula for calculating the mean electron density at a given altitude and shows the development and the assumptions made at the same time.

All above-mentioned launchings of geophysical rockets of the Academy of Sciences of the USSR were carried out in the middle latitudes of the European part of the Soviet Union. During the construction of the graph on the distribution of the electron densities, which are independent of altitude, data were used which had been obtained only from the ascending parts of the rocket trajectories.

During the rocket launchings of 1954--1957, 48- and 144-mc frequencies (with a three-fold multiplication of the smallest frequency) were used. During the experiment on February 21, 1958, additional registration was made of phase differences of 144-mc radio waves and of the coherent 24-mc waves which are also emitted from the rocket. During this launching, registration was made of the rotation of the polarization plane for all received radio waves, which occurred because of the magnetic splitting in the ionosphere. The final processing of the data for 1958 has not yet been completed, and the quoted data represent the average along approximately 10-km intervals of altitude. Of great importance is the fact that the geophysical rocket which reached an altitude of 475 km was stabilized in relation to three possible axes of rotation after rocket engine cut-off.

Results of some experiments are shown in Figs. 5--7. Local time is used in the legends under these illustrations. The data for 1957--58 allowed a conclusion that no other strongly pronounced layers exist at the observed altitudes, except in the F region. The ionosphere consists of very many small electron concentrations on the general background of a continuous increase of electron concentration up to the maximum of the F_2 layer. All this agrees with American data (Refs. 1--7). However, the measurement results conducted on February 21, 1958, on the maximum ionization of the F_2 layer disagree considerably with Berning's data (Ref. 6), according to which the electron concentration above the maximum layer drops rapidly and becomes very low at an altitude of 378 km. In our experiments this concentration varies from 1.8×10^6/electron/cm^3 to 10^6 electron/cm^3 at an altitude of 290 and 473 km, respectively. It should be mentioned that during these experiments the cycle phases of solar activity, seasons, and days were fully comparable in the United States and the Soviet Union.

The results of 1957--58 were comparable with the simultaneous measurements of the ionospheric stations located near the launching site of the rocket. At the same time, it appeared that the altitude registered by the ionospheric stations in the F regions actually exceeds the altitude which is obtained with the help of a dispersing interferometer by 50-150 km.

Extensive material and signal reception from the satellites and the level of intensity of these signals were accumulated during the existence of the Soviet artificial Earth satellites. This material is still being processed. Only selected investigations have been made so far.

The signal levels of the satellites' 20.006-mc-frequency radio transmitters have been investigated. By comparing the mean field intensity of actual signals with the intensities calculated by the formula of ideal radio transmission, radio-wave absorptions for various positions of the satellite were determined. Comparison of the absorption of radio waves when the satellite is located above the maximum ionization and below the maximum F_2 layer permits evaluation of the change of the ionospheric density above the maximum F_2 layer. According to these evaluations the drop of electron concentration above the maximum layer takes place considerably more slowly than the increase during the approach to the minimum from below.

It was noted in a number of cases that the radio waves pass the receiving point not along the shortest distance but by way of circling the Earth's sphere along a greater curve of a large circle. In some cases the measurements of the volume of field intensity proved to be larger than had been calculated by applying the law of inverse proportion of the first distance stage, which obviously gives evidence of the propagation of radio waves, in these cases through some peculiar channels of the ionosphere.

Furthermore, the "radio dawn" and "radio set" were investigated during the reception of radio signals from the satellite on the frequency of 40 mc. In several cases, we succeeded in observing the "radio dawn" and "radio set" of satellites in a pure form and in fixing the corresponding moments of time. The radio ray is subjected to a very strong distortion in the ionosphere. The delay of the actual "dawn" as compared to the actual "set" makes it possible to determine the value of the bending or distortion of the radio beam. Since the bending of the radio beam in the ionosphere depends on the change of the electron concentration with altitude, it is possible, by studying various laws of change of electron concentration, to choose, with a certain degree of uncertainty, such a distribution of electron concentration vs altitude which gives the time of "radio dawn" and "radio set" as is actually observed. To a certain extent, the effect of the lower layers can be taken into account on the basis of the direct measurements, which are carried out by the ground stations.

Data obtained during the observation of radio signals from the first two satellites allowed one to assume that the volume of electron concentration in the outer ionosphere decreases with increased altitude much slower than its increase below the maximum. Thus there exists a qualitative correspondence of such evaluations of the electron content in the ionosphere with those obtained by dispersion radio interferometers in rockets.

In addition to the utilization of radio waves emitted by the satellite for the investigation of the ionosphere, Sputnik III is equipped with an instrument for direct measurement of the concentration of charged particles in the ionosphere and the transmission of the readings of this instrument through the radio telemetry system. A special feature of this type of experiment is the independence of the measurement results from the characteristics of the entire ionosphere between the earth and the satellite and other processes which take place in it.

The experiment carried out by Sputnik III was proposed by K. I. Grinhauz and M. Zelikman (Ref. 15).

The ionosphere is quasi-neutral in that it may be considered that the concentration of positive ions equals the sum of electron concentration and negative ions. Therefore, the entire concentration of charged particles equals the double volume of concentration of positive particles. By measuring the latter the first can be determined.

The device mounted on Sputnik III for measurement of positive ions consists of two spherical perforated ion traps (Figs. 8-10) which are fastened to thin bars and mounted on diametrically opposite sides of the satellite (Fig. 9) and also of an electronic unit which contains two amplifier converters and a generator of sawtooth-like voltage impulses (Fig. 8). Each of the ion traps has the shape of a perforated sphere with a diameter of 10 cm (Fig. 10). There is a spherical collector in the center of each to which a negative potential is fed relative to the perforated cover (~ -150 volts). With this, the electric field inside the traps gathers on the collector all positive particles which fall into the trap and expells all negative particles from it.

The collector (Fig. 8) is connected to the conductive surface of the satellite through resistance. The current of positive ions gathered on the collector runs down to the surface of the satellite causing a corresponding increase of electron current from the surrounding environment to the surface of the satellite. The voltage from the input resistance advances towards the amplifier input, the output of which is connected to the radio telemetry system, which transmits the instrument readings to Earth.

The concentration of positive ions can be determined according to the formula given in Appendix B.

Because of various factors (velocity difference of electrons and ions, photoemissions of ions from the satellite's surface, etc.) the satellite may acquire an electrical charge as a result of which the potential of the perforated cover of the trap will differ from zero in respect to the surrounding environment. In order to calculate the influence of the satellite's electrical charge on the results of measurements, advantage is taken of the sawtooth voltage impulses which are fed to the perforated cover with respect to the body of the satellite.

During the moments of sawtooth impulse feed a simultaneous telemetrical record of the trap collector currents and the potential between the surfaces of the trap and the surface of the satellite permits one to obtain the volt-ampere characteristics of the current on the collector in relation to the variety of potentials between the perforated trap cover and the body of the satellite. The expected characteristic is shown in Figs. 11-15. The point A at which the drop of the collector current terminates during the potential increase of the perforated trap cover in relation to the surrounding environment corresponds to the potential of the decelerating ions that can be determined on the basis of the well-known expression given in Appendix C. Knowing the amplitude of the generator impulses and the decelerating potential of the ions, it is possible to find, on the curve of Fig. 11, the point which corresponds to the condition by which the potential of the perforated trap cover in relation to the surrounding environment will equal zero. Then the density of the ion flow through the trap represents their actual density in the ionosphere. This permits one to determine the actual value of the ion flow over a period of time between the two neighboring sawtooth impulses. The flow which corresponds to the deceleration potential is a summaric current created by parasitic processes.

The recording of collector currents during the absence of voltage inpulses on the traps permits one to measure the dimensions of small-scale nonhomogeneities of ionization.

At present, the processing of these experimental results is only in its primary stage, and, therefore, only some preliminary information characterizing the conducted measurements can be reported. We will limit ourselves to the discussion of measurements taken at two points of the satellite's orbit during the first day of flight. These results are typical, although other values were observed.

Every 2 sec, bi-polar intensity impulses in relation to the body of the satellite with an over-all length of 0.2 sec (Fig. 12), were fed to the perforated cover of the ion trap.

Figure 13 shows volt-ampere characteristics of the dependence of the collector trap currents on the intensity of the spherical trap covers at an altitude of 795 km on May 15, 1958, over a period of 5--6 hours in the afternoon at middle latitudes. The character of this dependence is as was anticipated (Fig. 11, Ref. 15). At the moment under discussion, one of the ion traps was located in the rarefied region formed behind the satellite, which caused the ion current in this trap to be very small. Full retardation points of positive ions may be noticed in these characteristics. If we consider that at this altitude the heaviest ion M_{max} is the ion of atmospheric oxygen (mass 16) and that, consequently, the kinetic energy of ions at the moment of total retardation is $E_T = (M_{max} \times v_{sp}^2)/2e \sim 5.1$ ev, it can be determined on the basis of the characteristics in Fig. 13 that the potential of a trap cover equals the potential of the surrounding plasma when it is fed with a voltage of +6.4 volts in relation to the body; consequently, the negative potential of the body of the satellite in relation to the plasma equals 6.4 volts. Such a potential of the satellite (even without consideration of the influence of a photo effect) may take place at an electron effective temperature on the order of tenths of thousands °K, i.e., at such a temperature which, in the case of a Maxwell velocity distribution of electrons, leads to the indicated negative potential of the body without accounting for the influence which the photo emission from the surface has on it. The concentration of positive ions, which is determined by the current corresponding to the zero potential of the trap cover in relation to the plasma, equals 1.9×10^5 ion/cm^3.

The perforated trap cover actually appeared to be connected in parallel with spherical Lanquir probes when the voltage impulses were fed to them. During the passage of a positive voltage impulse through the trap cover in relation to the satellite body, the electron flow of these probes sharply increases, causing the drop of voltage on the output of the generator of sawtooth-like impulses. Taking advantage of the fact that the difference in the form of positive voltage impulses from its undistorted form is known, it is possible to construct the following probe characteristic

$$\lg I_3 = f(V)$$

where I_3 is the sum of the current exerted on both trap covers. By it is determined the point at which the potential of the satellite equals the potential of the plasma and also the electron temperature.

Figure 14 represents the dependence of the summaric current in both perforated trap covers on the potential (probe characteristic) for the same experiment, as in Fig. 13 (H = 95 km, May 15, 1958). The potential which was determined by this characteristic corresponds to the potential of the plasma, which is close to the one determined by the volt-ampere characteristics of ions flows, and the electron temperature is not less than 15,000°K.

In many cases (at lower altitudes) the positive voltage impulse decreases as a result of the voltage decrease caused by the electron currents on the perforated trap cover to such a degree that the full deceleration of positive ions does not take place. For example, one may point to the volt-ampere characteristics obtained at an altitude of 242 km, on May 15, 1958, over a period of 1 to 2 hours before noon in the middle latitudes (Fig. 15). In order to determine in these cases the point at which the potential of the perforated cover equals the potential of the plasma, it is necessary to use only the probe characteristics. Two curves represent the current at various collectors. In the given case, at an altitude of 242 km, the concentration of positive ions proved to be 5.2 x 10^5 ions/cm^3, the negative potential of this satellite being approximately 2.0 volts and the effective electron temperature being approximately 7000°K.

The ion content of the upper atmosphere was also determined by rockets and by Sputnik III.

CONCLUSION

1. Observations of radio waves emitted from artificial Earth satellites and recorded during various positions of the satellite in relation to the maximum ionization layer F_4 can serve as sources of valuable information on the properties and content of the ionosphere. In the future the scope of these observations should be widened. It is particularly necessary to study the simultaneous passage through the ionosphere of radio waves of various frequencies.

2. In the meantime other investigations of the ionosphere conducted in the Soviet Union with the help of rockets and artificial satellites make it possible to obtain the following results:

   a) The ionization above the maximum of F_2 layer drops very slowly with altitude, which indicates a very large altitude scale for ionized particles of the ionosphere;

on February 21, 1958, at an altitude of 473 km, an ionization of about 10^6 electrons/cm^3 was discovered; on May 15, 1958 at an altitude of 795 km, a concentration of positive ions was measured which reached 1.9×10^5 ions/cm^3.

b) The effective electron temperature in the F regions and higher is many times larger than the temperature of the environment.

c) It was confirmed that the ionosphere below the maximum F region, contrary to the pattern which was established on the basis of data from an ionospheric probing from the Earth, does not possess any sharply expressed layers and is characterized by a series of small maxima with a monotone growth of electron density upwards to the maximum of the F layer.

d) It is confirmed that the maximum of the F_2 layer, and ionization in general below the F region, is located at 50 to 150 km below the values which were obtained from data of usual ionospheric probing from the Earth.

The obtained material is of great interest in the physics of the upper atmosphere. The large altitude scale for electrons above the maximum of the F_2 layer and the high effective temperature of electrons correspond favorably with the conception of an intensely heated upper atmosphere with a large altitude scale. This is a result of observations of deceleration of artificial Earth satellites. Of very great interest is the absence of the thermodynamical equilibrium between the electrons, ions, and other particles of the upper atmosphere. It is quite possible that electrons of the outer atmosphere are accelerated in the short cycle variable geomagnetic fields, where they are created by the circulation of the atmosphere or interplanetary environment and are causing the upper atmosphere to heat up.

The structure of the ionosphere (which consists of many finely stratified layers below the maximum of the F_2 layer) and the fact that its location is lower than was originally assumed on the basis of direct radio probing from the Earth require a serious review and correction of old assumptions. Obviously, an ordinary ionospheric probing gives a less clear picture of the ionosphere than an investigation facilitated by rockets and artificial Earth satellites. It is evident that all this does not detract from the practical value of ionosphere probing, which was and is a practical means for obtaining effective parameters of the ionosphere. However, an exhaustive and thorough investigation of the ionosphere is possible only with the help of rockets and artificial Earth satellites. We have made significant progress in this direction. Before us are fascinating perspectives to investigate the upper, outer atmosphere at greater and greater distances from the surface of the Earth.

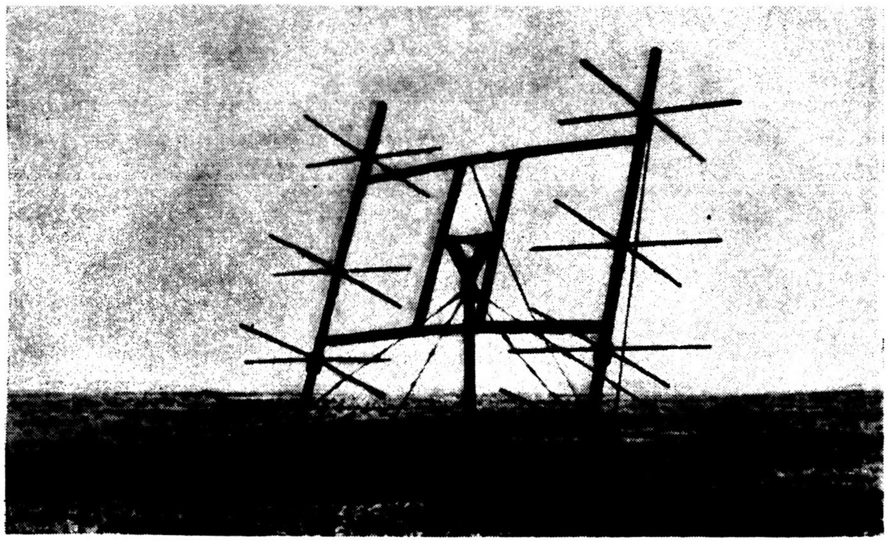

Fig. 1. View of Receiving Antenna During the Test with an Ultra-Short-Wave Dispersion Interferometer

Fig. 2. Phasometric Receiving Installation of the Dispersion Interferometer

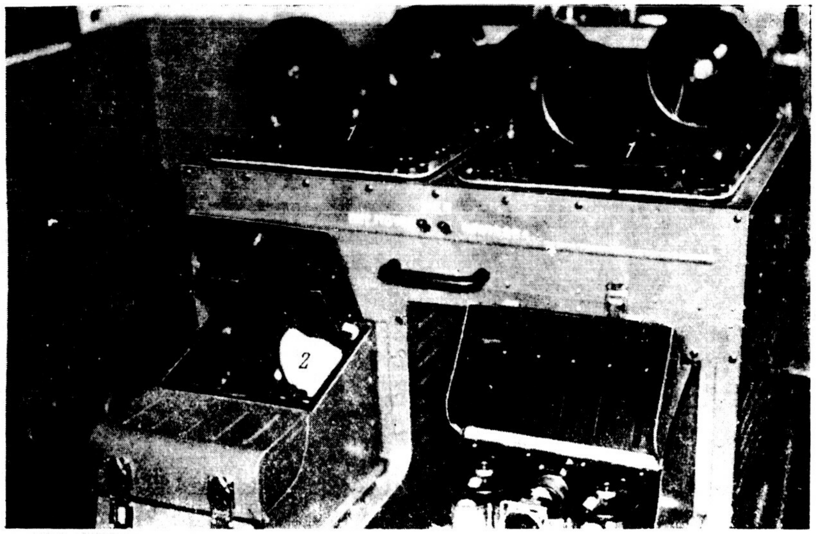

Fig. 3. Register Oscillographs of the Dispersion Interferometer
(1- Repeating oscillograph; 2- tube for the registration of characteristic points of the Lissajous figures; 3- photo recorder)

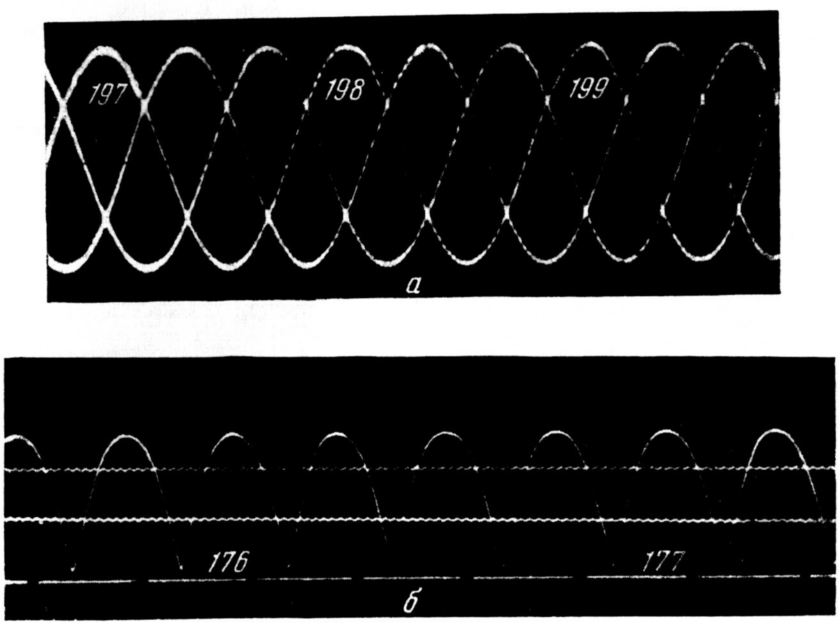

Fig. 4. Recording Samples
(a- Transposition of characteristic points of the Lissajous figures; b- Transpositions of interferential frequencies)

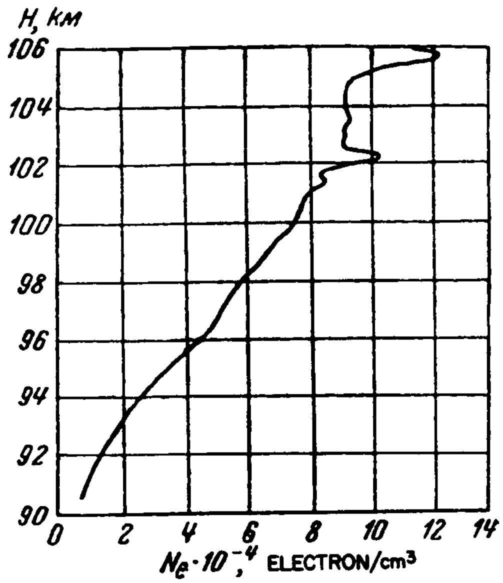

Fig. 5. Distribution of Electron Concentration with Altitude, 5:24 p.m. May 26, 1954

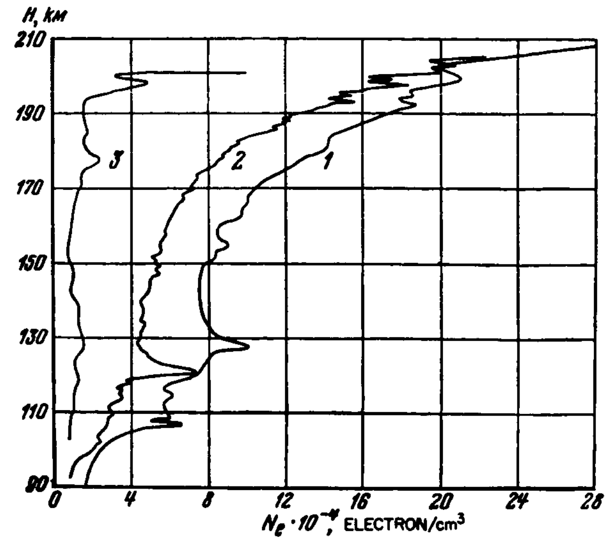

Fig. 6. Distribution of Electron Concentration with Altitude (1- 6:18 a.m. May 16, 1957; 2- 6:27 a.m. August 26, 1957; 3- 7:54 p.m. September 9, 1957)

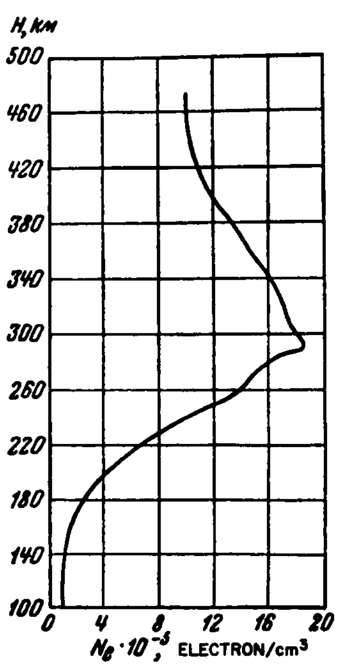

Fig. 7. Distribution of Electron Concentration with Altitude, 11:40 a.m. February 21, 1958

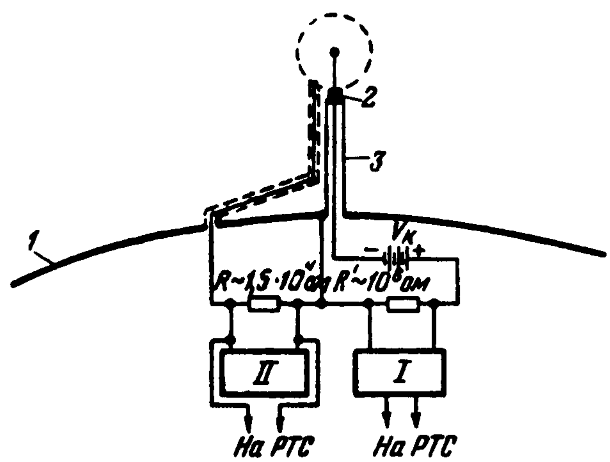

Fig. 8. Diagram of the Experiment with Ion Traps (1- surface of satellite; 2- isolator; 3- installation of screen tubes)

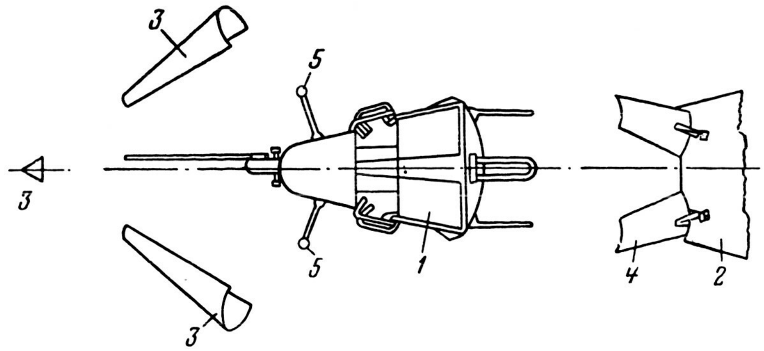

Fig. 9. Diagram of Location of Traps on the Satellite at the Moment of the Satellite's Separation from the Rocket Carrier
(1- Sputnik III; 2- rocket carrier; 3- separating protective cone; 5- ion traps)

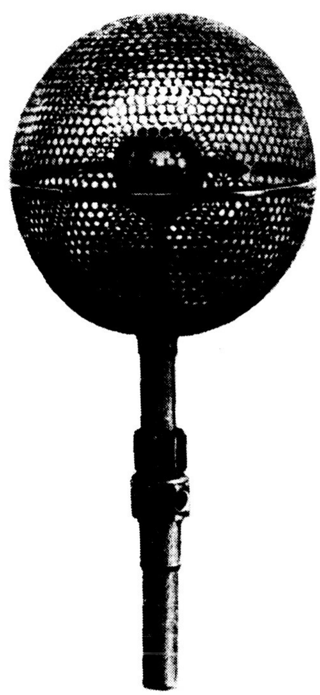

Fig. 10. Over-all View of an Ion Trap

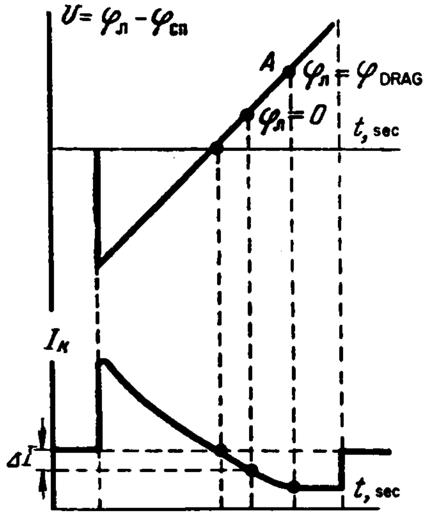

Fig. 11. Shape of Sawtooth Voltage Impulses (Upper Curve), Which are Fed to the Perferated Trap Cover, and the Form of the Anticipated Signals (Lower Curve)

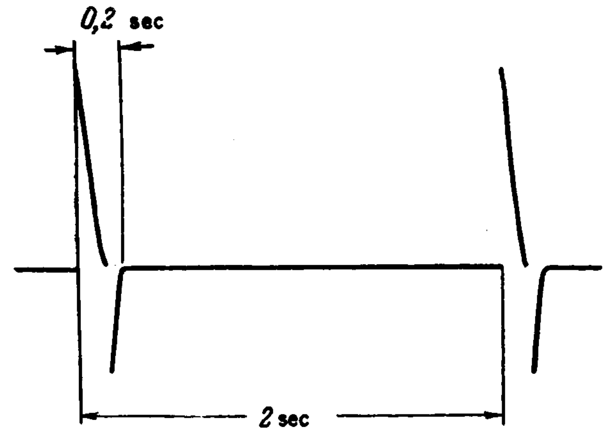

Fig. 12. Supply Diagram of Sawtooth Impulses per Time

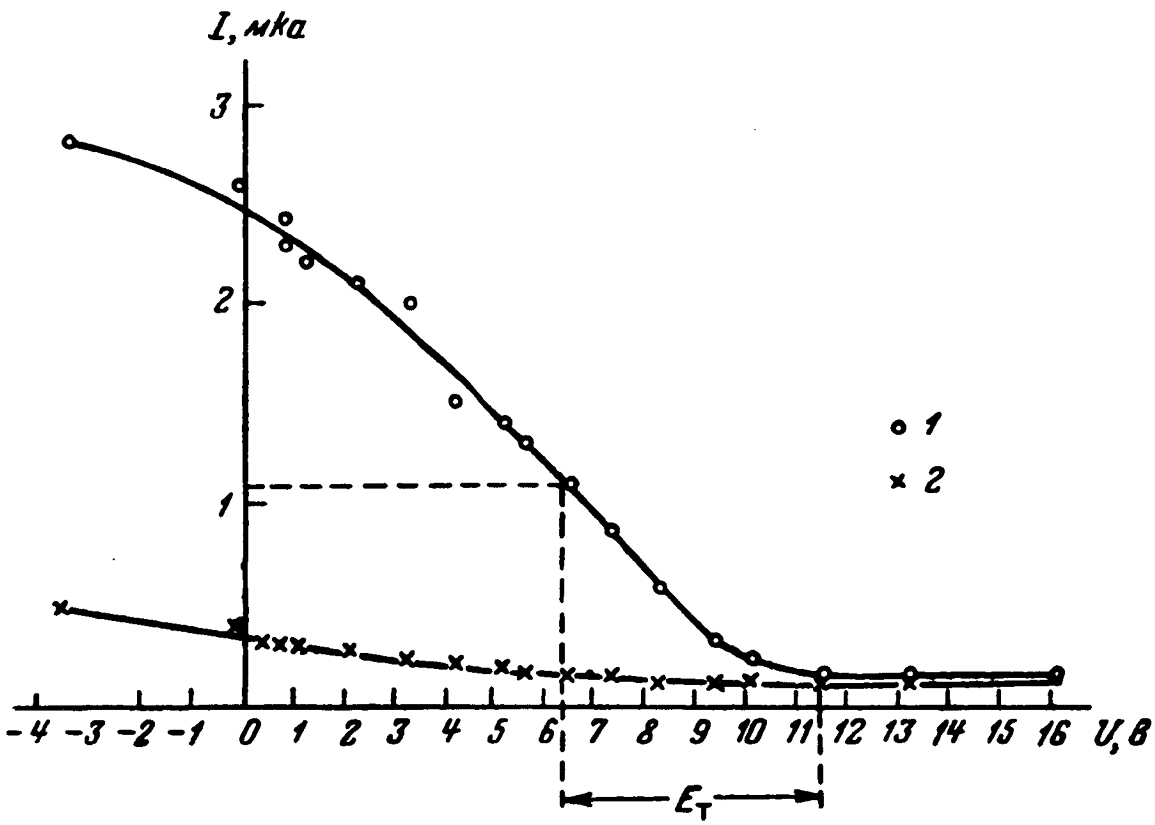

Fig. 13. Example of the Dependence of Collector Currents of the Ion Traps from the Potential of the Perforated Cover
(1- the current of the first collector; 2- current of the second collector)

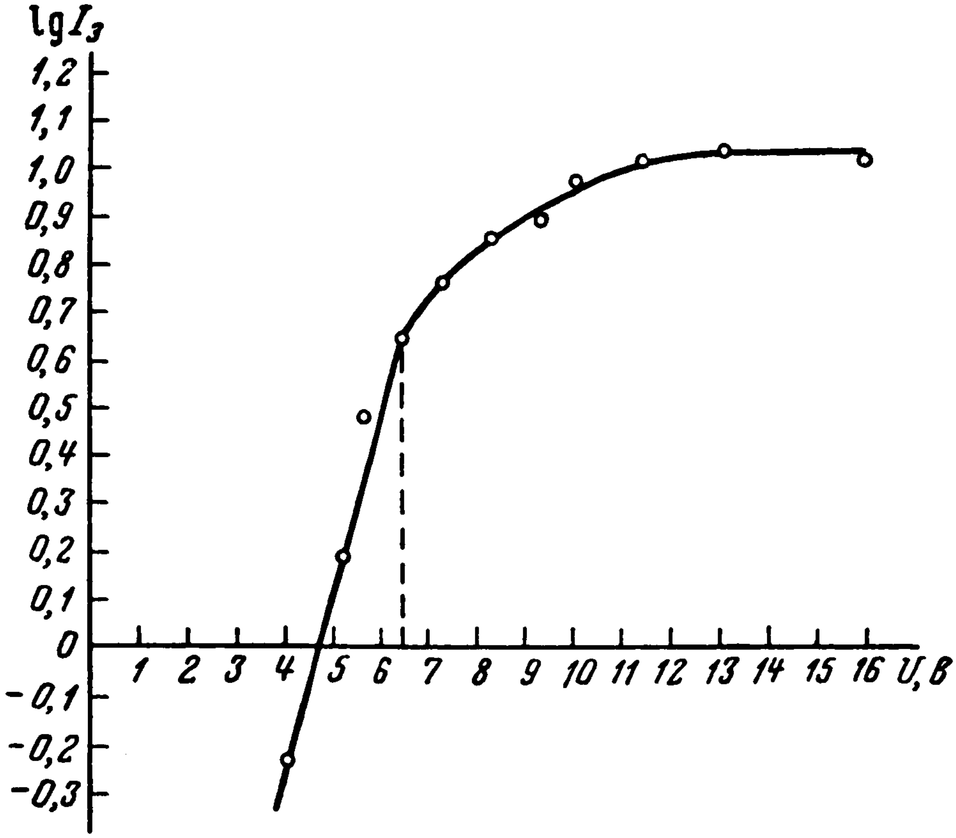

Fig. 14. Probing Characteristics

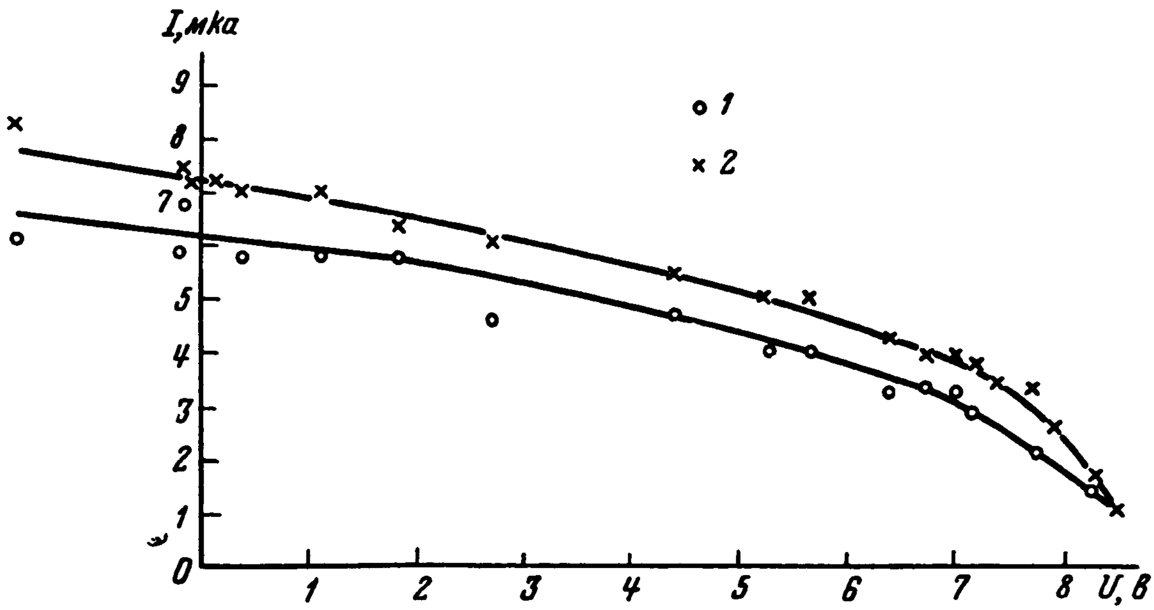

Fig. 15. Dependence of Ion Current on the Retarding Voltage
(1- current of first collector; 2- current of second collector)

APPENDIX A

It is assumed that

$$n_f = \sqrt{1 - \frac{Ne^2}{\pi m f^2}} \approx 1 - \frac{Ne^2}{2\pi m f^2} \tag{1}$$

where n_f is the refraction coefficient in the ionosphere for the frequency f, N is the effective concentration in electrons/cm^3, and e and m are, respectively, the charge and mass of an electron.

Because of their dispersion (referred to higher frequencies) the phase difference φ at the receiving point of two radio waves can be expressed as follows:

$$\varphi = \frac{2\pi pf}{c} \int_0^L (n_{pf} - n_f)dl \tag{2}$$

where L is the distance between transmitter and receiver, p is the relation of radio wave frequencies of a higher frequency with a radio wave of a lower frequency, and c is the velocity of light in cm/sec. The change of $\Delta\varphi$ during the change of L from L to L + $\Delta\varphi$, taking equation (1) into consideration, is represented as follows:

$$\Delta\varphi = \frac{e^2}{mcf}\left(\frac{p^2 - 1}{p}\right) \int_L^{L+\Delta L} Ndl \tag{3}$$

and the mean value of N along the track of ΔL is

$$\bar{N} = \frac{1}{\Delta L} \int_{L}^{L+\Delta L} NdL = \frac{cmf}{e^2} \times \frac{p}{p^2-1} \times \frac{\Delta\varphi}{\Delta L} \quad (4)$$

It is assumed that during the changing period of L to the volume ΔL the volume of $\int_0^L NdL$ does not change. The difference of ΔL from Δh, which is the altitude increase above the Earth's surface, is taken into account during the processing of the measurement results.

APPENDIX B

If the ion trap is located within a flow of ionized gas, the measured collector current will be

$$I_+ = N + ev_{sp}\pi r^2 \alpha f(\varphi_L)$$

where e is the electron charge, r is the radius of the perforated superficial trap, α is the coefficient of its transparency, v_{sp} is the velocity of the satellite, and φ_L is the potential of the perforated trap cover in relation to the surrounding environment.

APPENDIX C

The deceleration potential can be determined from the relation

$$e\varphi_T = \frac{M_{i\ max}V_{sp}^2}{2}$$

where e is the electron charge, $M_{i\ max}$ is the mass of the heaviest ion falling into the trap, and v_{sp} is the velocity of the satellite.

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7. PRELIMINARY REPORT ON GEOMAGNETIC MEASUREMENTS BY THE THIRD SOVIET EARTH SATELLITE

S. Sh. Dolginov, L. N. Zhuzgov, H. V. Pushkov

Geomagnetic measurements with artificial Earth satellites were part of the program of scientific research of the national committees of the US and the USSR for the IGY. The scientific value of these measurements has been discussed by American authors in a number of articles (Ref. 1). Of the Soviet papers devoted to this question, the ones by N. V. Pushkov and S. Sh. Dolginov (Ref. 2) are worth mentioning.

In accordance with the plan of scientific investigations during the IGY, the first geomagnetic measurements were planned and accomplished with the third Soviet artificial Earth satellite.

Other geophysical experiments having a direct relationship to magnetic and electrical phenomena in cosmic space were planned and carried out simultaneously with geomagnetic measurements, using the third Soviet artificial satellite. The large number of instruments which were installed on the satellite created additional difficulties in regard to accurate measurements of the magnetic field intensity which is due to the magnetic deviation caused by the satellite's instrumentation. As a result of an examination of the conditions for magnetic measurements to be made with the satellite, it was decided to conduct these measurements with the help of a magnetometer with magnetically saturated elements which can be automatically adjusted to the direction of the field vector.

Magnetometers of this type are comparative instruments and are less accurate than precision proton magnetometers; however, they have the following advantages:

1. These magnetometers are less sensitive to the heterogeneity of the magnetic field and variable magnetic-electrical disturbances. Field heterogeneity and variable disturbances affect only their operating stability and accuracy but do not hinder signal formation.
2. With the help of these magnetometers it is possible not only to measure the field strength but also to determine the satellite's orientation at different time periods, which is necessary for the processing of data from other experiments.
3. A magnetometer of this type is much more readily adaptable to the applicable telemetry system.

Without going into detail concerning the magnetometer's construction (a description will appear in another paper), we will point out only that the instrument is of a double frequency harmonic-type magnetometer.

In contrast to instruments of this type which are used for aeromagnetic surveys, this magnetometer makes it possible to conduct measurements at any magnetic latitude and during any orientation of the satellite. This magnetometer is fully automatic, requires little power, and is of comparatively low weight. There is also a special attachment which permits one to obtain information on variations of the satellite's orientations in space and the character of its rotation.

The instrument's range of measurement is 48,000 γ. The servo-system response rate is 40--45 deg sec. The sensitivity of the magnetometer can be judged by the curve in Fig. 1. The graph in Fig. 2 gives a conception of the stability of the magnetometer in the course of time. These graphs indicate the readings of the instrument at the observatory and the field variations ΔT during the testing period of the instrument (Greenwich time), which were measured by observatory variometers. The average zero drift is on the order of 2 γ/hr. The magnetometer zero index was determined by comparison with a proton magnetometer.

Initial processing of the observation material is being conducted at the present time. A geophysical interpretation of the results will be given after the completion of the processing. The graphs presented illustrate the nature of the material being obtained.

Curves 1 and 2 in Fig. 3 represent the readings from two potentiometer detectors, which characterize the angular displacement of the satellite. According to the control graph of the satellite's angular position, it is possible to obtain a numerical value of the comparative change of the satellite's position in space at any given moment. From these curves it follows that the satellite completes a precession movement with a period of T = 136 sec. Furthermore, the satellite rotates around its axis with a velocity of approximately 0.36 deg/sec. There is a basis for the assumption that it will also be possible to determine the absolute orientation of the satellite in space in relation to the determined system of coordinates.

Curves 3 and 4 of Fig. 3 also represent the magnitudes of the magnetic field which were measured directly by a magnetometer over a period of 23 minutes, on a segment of a trajectory within an altitude range of 250--750 km. It follows from curves 3 and 4 that the magnetographs which are being obtained from the satellite loosely represent variable curves modulated by magnetic interference, which is sharply related to the shell of the satellite. The modulation period equals a period of precession.

The magnetic influence of the instrumentation aboard a satellite was experimentally determined under laboratory conditions. The maximum value of the magnetic deviation is about 3,000 γ. With such values of magnetic disturbances we may consider that the magnetometer of the satellite genuinely measures the intensity of the Earth's magnetic field and the projection of the magnetic disturbance vector on the direction of the Earth's field. Thanks to the precession of the satellite, the magnitude of the projection changes periodically in value and symbol, which permits one to exclude the basic element of magnetic disturbances.

The comparison of the measured values of the magnetic field intensity which pertain to the intersections of the ascending and descending curves permits one to control the stability of the zero point on the magnetometer during the entire operation of the instrumentation. The magnetic recordings of satellite instrumentation and the intensity curves which were constructed by the data of leveled magnetic charts of the surface values for points which are located at the intersections of the orbital plane and the Earth's surface coincide very well (by the character of curve variations). A comparison of these curves is used as a standard during the initial processing of the material.

An examination of initial data permits observation of particular points which are distinguished by comparatively brief but rapid variations of the magnetic field. An example of such variations is shown in Fig. 4. They pertain to a moment of time and coincide with a passage of the satellite through a region of the ionosphere. The point in question pertains to the time interval of 10:46:11.5 to 10:46:16 on May 16, 1958.

Similar phenomena are being encountered on the photorecordings of material which has not been processed yet. An interpretation of these phenomena will be given after examination of all such cases. It is proposed to carry on a study of experimental data obtained in the following directions:

1. To make a comparison of the field values measured by the magnetometer at different heights and computed according to the theory of potential. There is also one of the most recent harmonic analyses of ground data that will be used as the basis for the computation.
2. To make a comparison of the isoline of a full force magnetic field and the intensity of cosmic rays as measured by the satellite.
3. To make an analysis of the field above the East Siberian world magnetic anomaly, which has been well studied during a ground aeromagnetic survey and passed over many

times by the satellite. The objective of the analysis will be to check the hypotheses on the depth at which its source is located.

4. To analyze materials in order to clarify the reality of the existence of such systems in the upper atmospheric layers.

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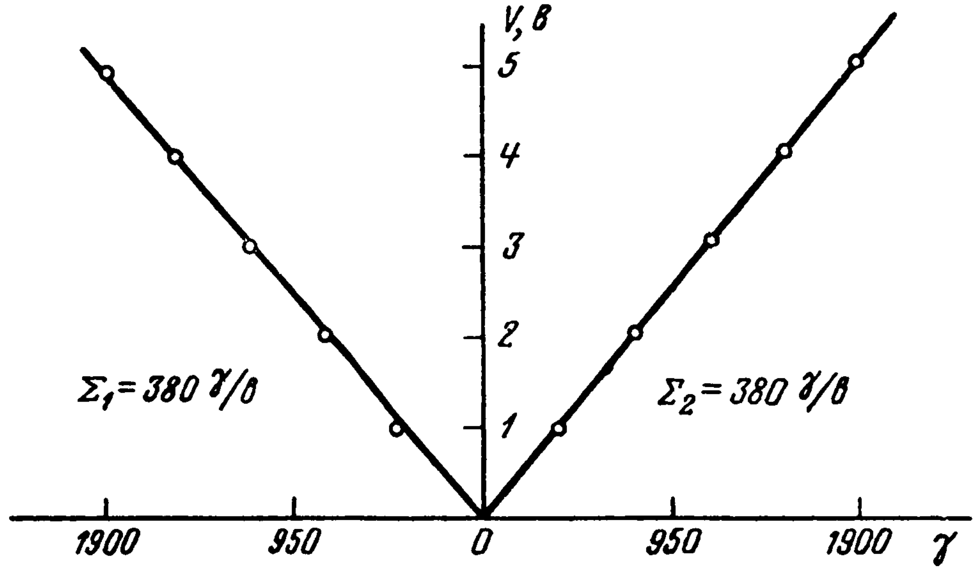

Fig. 1. Sensitivity of Σ Channels of the Magnetometer SG-45

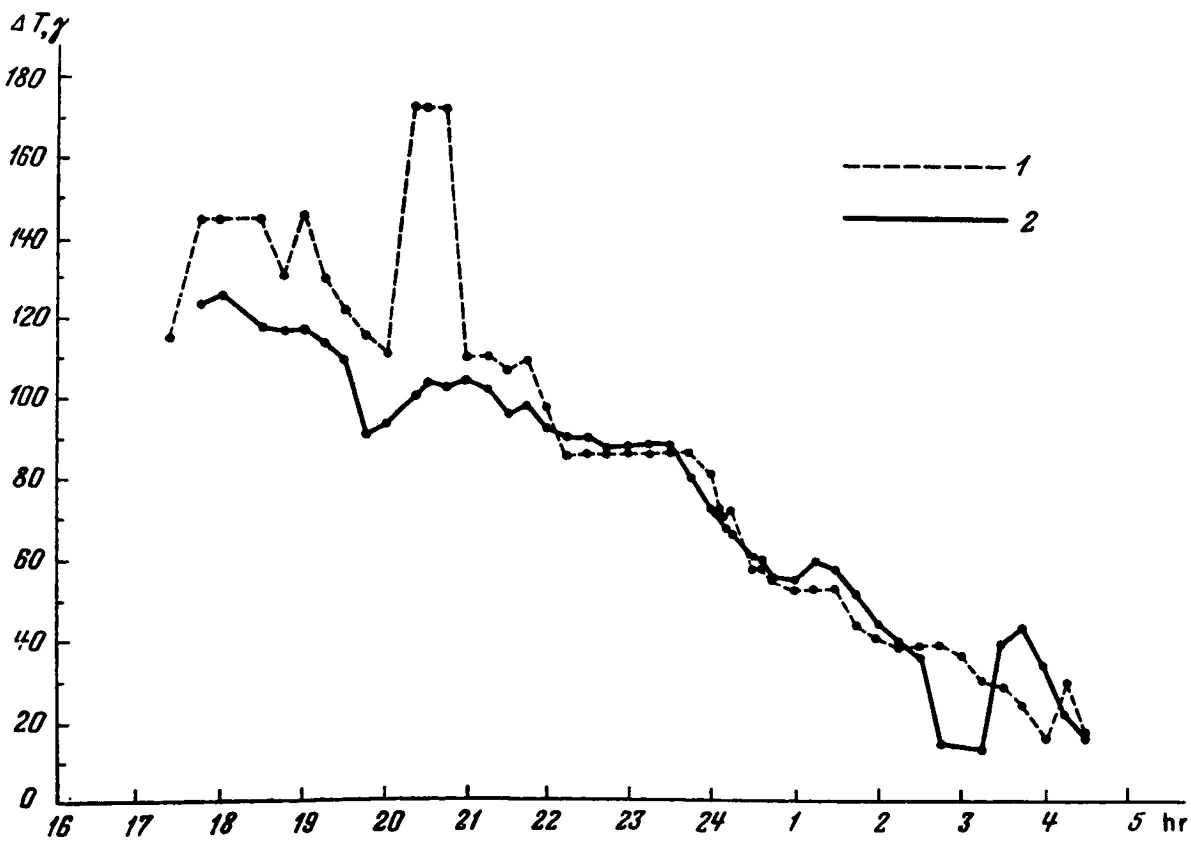

Fig. 2. Change of Intensity of Full Vector ΔT on March 11-12, 1958
(1- Readings of SG-45 29153; 2- readings of observatory magnetograph)

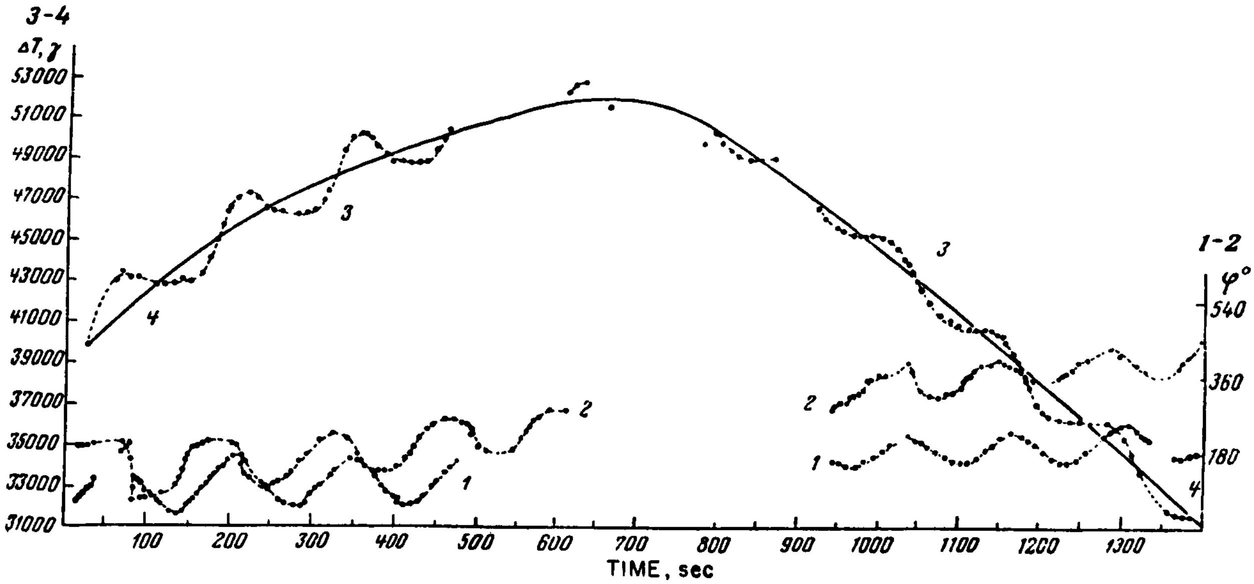

Fig. 3. Magnetometric Graphs (1, 2- channels of orientation; 3,4- change in intensity of magnetic force)

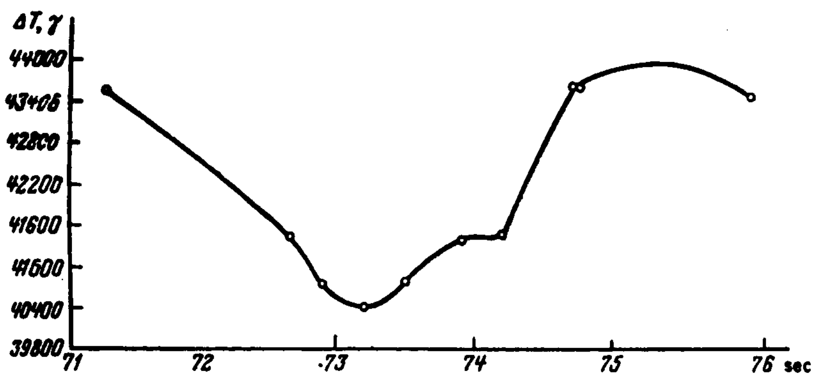

Fig. 4. Peculiar Point, Received on May 16, 1958 Between 10:46:11 a.m. and 10:46:16 a.m.

8. INVESTIGATION OF MICROMETEORITES WITH ROCKETS AND SATELLITES

O. D. Komissarov, T. N. Nazarova, L. N. Neugodov,
S. M. Poloskov, L. Z. Rusakov

Up to the present time the basic information on hard components of interplanetary matter was obtained by various methods such as visual, photographic and radio-location tracking of meteors, observation of zodiac light, etc. Evaluations of space density of meteoric bodies were made on the basis of these investigations.

Recently, the Soviet Union and the United States of America have begun an investigation of meteoric particles by direct methods, i.e., with the help of instruments launched into the upper atmosphere in rockets and satellites. In order to register meteoric particles with rockets and satellites, we are utilizing an instrumentation which registers the number of impacts and conducts measurements of some mechanical parameters of meteoric particles.

The conception of measuring instrumentation consists of the following: from the point of view we are interested in, each particle may be characterized by its momentum and energy (or by mass and velocity). It is not possible to detect the momentum of the meteoric particle at the instant of impact because the particle explodes on the surface of the detector, causing the momentum of the detector material which is emitted during the explosion to exceed considerably the momentum of the particle itself. When measuring this "reactive" impulse which is recorded by the detector, we obtain not the impulse of the meteoric particle but (with a certain scale factor), obviously, its energy.

Theoretical calculations conducted by K. P. Staniukovitch showed that, for great velocities, the detector momentum is proportional to the energy of the particle hitting the instrument. Presently, theoretical research and laboratory experiments are being conducted in order to determine this relationship. It is possible that the exponent of the velocity in the expression $mv^2/2$ may turn out to be not 2 but somewhat less.

The momentum measurement should naturally be carried out by means of a ballistic detector. Though the time of collision is negligible (about 10^{-8} sec), it appeared expedient to choose the natural frequency of the detector as about 400 cps. The detector is constructed as follows: a massive plate is suspended by means of a flat spring to which four piezoelectric cells of ammonium phosphate are connected (Fig. 1). We have utilized not one but four piezo elements in order to decrease the dispersion which is transmitted by the detector due to the output voltage dependance of the meteoric particle at the point of impact. The deformation of the piezo elements due to impacts of micrometeorites produces a voltage output in the form of short-term damped oscillations which are separated according to amplitude into four ranges by the amplifier converter; this converter counts the number of pulses in each amplitude range. The block diagram of the converter is shown in Fig. 2. This diagram shows clearly that the signal of each detector is received by separate amplifiers; this eliminates shunting of the detectors by each other because of their own capacity.

The signals are separated according to amplitude by feeding the output of the appropriate amplifier to the counter for each amplitudinal range. The four amplifier outputs corresponding to the four ranges are compounded; thus the counter performs a parallel calculation and adds the number of signals in each amplitudinal range.

In order to eliminate repeated actuation of the first triggers by the half waves of a signal originated by the damped oscillation, a Kipp relay is located at the entrance of each circuit which closes the entrance of the calculating circuit for a period of 0.06--0.08 sec. This sets the resolving power of an entire system to 12--17 impacts/sec.

The calculation circuit with the most sensitive range consists of six triggers and conducts calculations up to 32. The signal on the Kipp relay of this calculating circuit is taken from the last stage of the amplifier and, without limitation, secures the registration of the detector signals with a magnitude of 0.001 volt and up.

Correspondingly, the calculation circuit of the higher ranges has five triggers with a calculation ability to 16 and three triggers with a calculation ability to 4; the signals are taken from the intermediate stages of amplification.

The signal of the least sensitive range on the Kipp relay is taken without amplification from the adding circuit, which consists of resistors. The calculation circuit of this range has only one trigger; that is, it registers each signal.

The voltage of the output flip-flop of the counter circuit is fed to the output circuit, which produces fixed levels that maintain a ratio of 1:2:4:8. Thus, any condition of the output triggers creates a fixed intensity at the output, which easily permits one to determine the condition of each output trigger at any moment of time and, consequently, the number of signals passed to this moment in each range.

The indicated output circuit permits one to transmit, through a single radio telemetric channel, the number of signals which pass through all four ranges.

A record of registration by a radio telemetric system is shown in Fig. 3. The variation in the height of the level confirms the registration of the number of impacts by the counting circuit which pertains to the corresponding amplitude range. Thus, our detectors measure the impulse which affects their surface. The calibration of such detectors for impulse load is done as follows: the detector is placed in a horizontal position and, from a certain height, we drop a ball on it. After the impact, the ball bounces off the detector plate and attains a certain height. Knowing the height from which the ball was dropped and the height of rebounce, we simultaneously receive the impulse which was fed to the detector.

This method fully imitates an explosion on the surface of a detector. Actually, the period of collision of the ball is about 10^{-5} sec. Even though this is 3 orders larger than for any meteoric particle, it is also much larger than the frequency of the detector itself. Consequently, the detector works under the same regime as in actual conditions, namely, measuring an impulse.

The calibration of detectors was conducted with balls with a mass of 0.6×10^{-3} to 2 grams. By varying the balls and the height of drop, it was determined that the detectors which we used work in a linear range from 0.1-1,000 grams cm/sec. Figure 4 shows the relationship between the corresponding sensitivity of the system and the impulse of the ball. Inasmuch as we would like to show in this graph only that the detector registers an impulse in the above-given range, the corresponding sensitivity S/S_0 can be laid on the axis of the ordinate, where $S = Ub/mv$, the sensitivity of the system, and S_0 is its nominal value, which may vary depending on the construction of the detector and converter because of the noise level on the satellite, etc.

The temperature variation of the detector in an interval ±60°C changes its sensitivity by ±5%, whereby the increase and decrease of temperature causes a respective increase and decrease in sensitivity.

If we proceed from the most elementary theoretical law of dependence between the momentum received by the detector and the energy of meteor particles, plus the momentum energy conversion factors calculated by K. P. Stanukovich, and assume that the mean velocity of meteor particles is 40 km/sec, the utilized detectors will permit us to measure the energy of the meteoric particles with a mass of 10^{-9} and more until the detector breaks down.

As mentioned before, the sensitivity of the system may be increased. Thus it is possible to measure one of two values which characterize mechanical properties of meteoric particles, perhaps the most important one, since the satellite's surface erosion is also connected with particle energy.

The third Soviet artificial Earth satellite is a laboratory in cosmos. It contains a considerable amount of research and auxiliary instruments, some of which create during their functioning a vibration of the satellite itself, which, if an incorrect choice of sensitivity limits is made, may cause the registration of not only meteoric impacts but the vibration of the satellite as well. In order to decrease the effect of such vibration, the detector was supplied with rubber shock absorbers which considerably decreased the sensitivity of the detector to this type of noise and vibration. However, we did not succeed in eliminating this condition entirely. In order to eliminate false signals, the sensitivity of the system was established above the level of noise from the satellite.

After all of the steps were taken, the instrumentation proved to be insensitive as far as vibration associated with the satellite is concerned; however, it is not insensitive to the more vigorous vibrations and noises which accompany the flight of the carrier rocket along the powered part of its trajectory. This, however, is not important since the measurements begin after the separation of the satellite from the rocket carrier. It should be mentioned that the detector possesses some sensitivity to impacts of meteoric particles on the surface of the satellite. In this case, the sensitivity of the detector drops by about 15 times and more. However, during an impact between a particle and the body of the detector, its sensitivity drops only by approximately 2. This condition was taken into account during the processing of the experimental data.

For the purpose of registration of meteoric particles, four detectors with an over-all area of 3410 cm, including the body of the detectors, were installed on the bottom of the satellite. All detectors are located in one plane. Since the location of the satellite in space is known from the data of the magnetic instruments and the solar orientation detectors, the location of our detectors is naturally also determined in space.

According to preliminary data, the detectors have registered an average impact frequency of about 1.7×10^{-3} impacts/m^2/sec, or 4.4×10^{-12} g/m^2/sec (for two astral magnitudes). Together with such a density of meteoric matter, a short, sudden increase of the number of impacts was registered.

During the satellite's flight in orbit the detectors have registered various impact frequencies. This result cannot be attributed to the variation of the number of meteoric particles in relation to altitude, since during the satellite's flight in orbit not only did its altitude change rapidly but at the same time its location in space was altered. While rotating and precessing, the satellite had different orientations relative to the Earth when passing various portions of the orbit, and sometimes the detectors were protected by the Earth from hits by meteoric particles. It is possible that the change of the number of impacts during the satellite's motion is also determined by the direction of the meteor flow.

At the moment of sharp count increase at an altitude of 1700--1800 km, the detectors recorded an average impact frequency of about 22 impacts/m^2/sec. At altitudes of 1300--1500 and 500--600 km, averages of 10 and 9 impacts/sec were registered within an area of 1 m^2.

If we should proceed from the assumption that an impulse which has been received by the detector during an impact with the particle is proportional to its energy, then the registered meteoric particles shall possess an energy of about 10^4 erg.

In conclusion, the authors would like to express their most sincere appreciation to A. K. Bektabegov, M. A. Isakovich, G. M. Kurtev, N. A. Rozin, N. A. Roy and A. A. Truchachev for their active part in this work.

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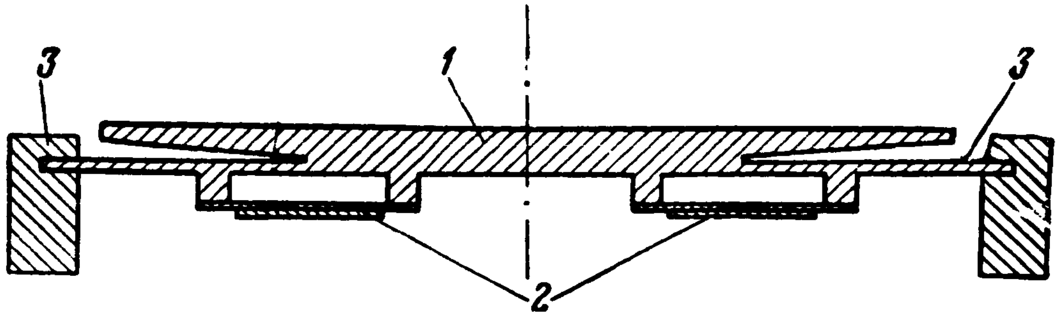

Fig. 1. Ballistic Piezo Detector
(1- plate; 2- piezo element of ammonium phosphate; 3- flat spring)

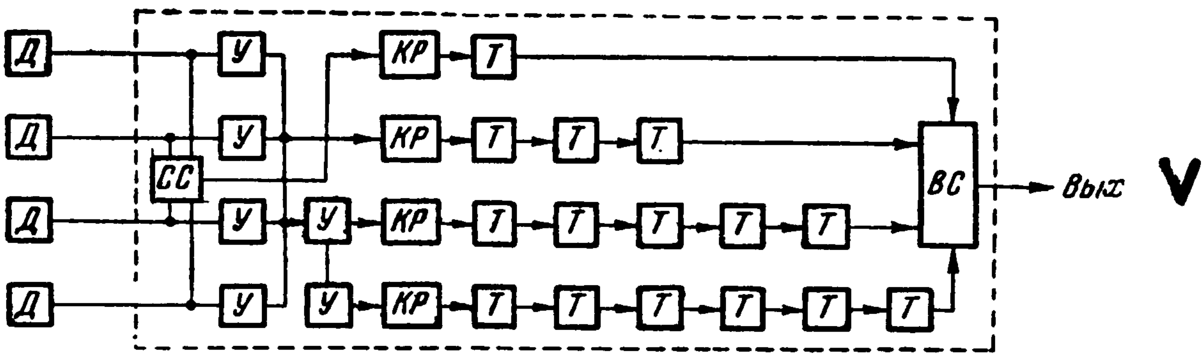

Fig. 2. Block Diagram of Transformer Amplifier
(D-detector; SS-composition diagram; U-amplifier; KR-kipp relay; T-trigger; VS-output scheme; V-output to telemetry)

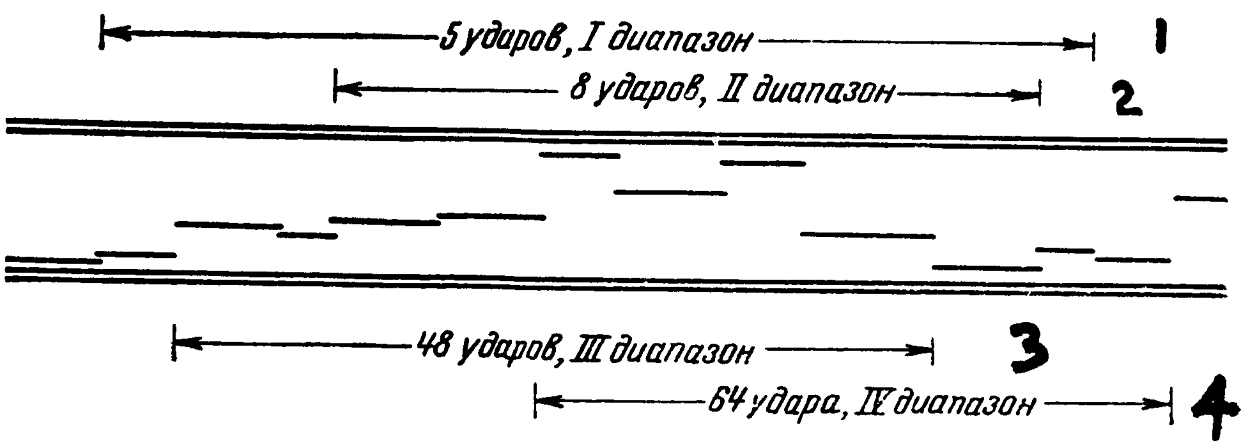

Fig. 3. View of Recording on a Radio-Telemetry System
(1- five impacts, range I; 2- eight impacts, range II; 3- forty eight impacts, range III; 4- sixty four impacts, range IV)

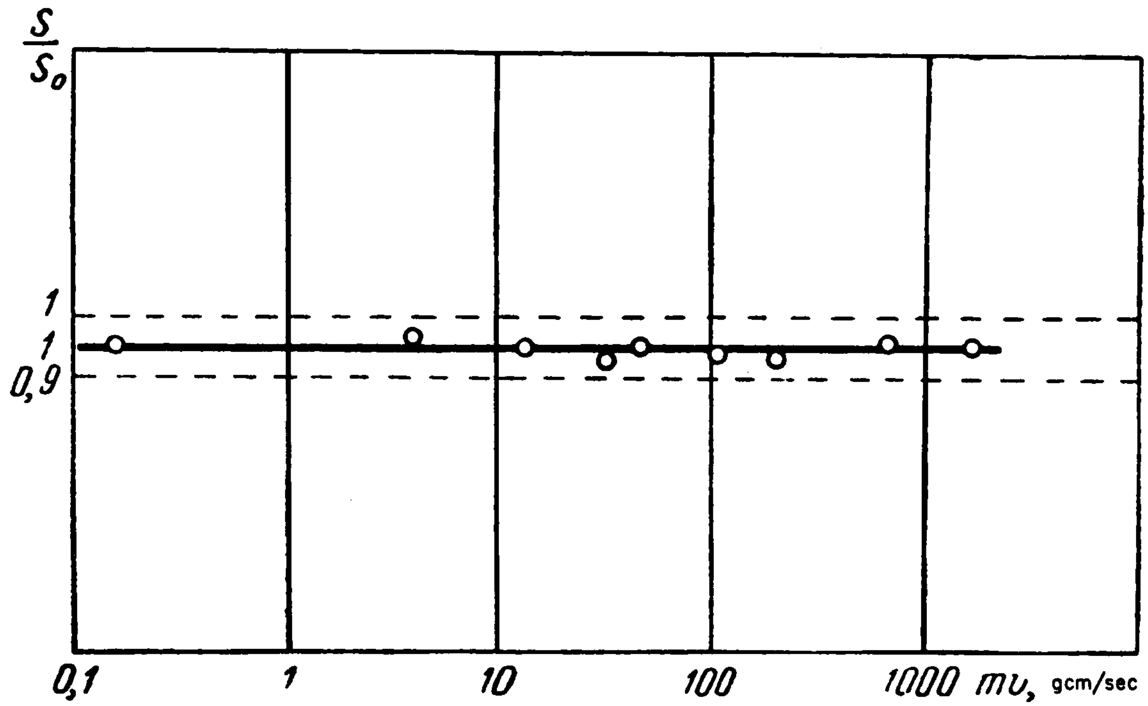

Fig. 4. Calibration Curve of System

9. DISCOVERY OF CORPUSCLES WITH THE HELP OF SPUTNIK III

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We have made an attempt to discover corpuscular fluxes with Sputnik III (Ref. 1). For this purpose two fluorescent screens of ZnS (Ag) (2×10^{-3} g/cm^2) covered with aluminum foil of 8×10^{-4} and 4×10^{-4} g/cm^2 were used as indicators. In front of screens of 5-cm diameter three aluminum diaphragms of 5 mm thickness were located, the input windows of which have secured the capture of corpuscles from a solid angle of 1/4 sterad. The radiation of the fluorescent screens was registered by photoelectronic amplifiers. The received electrical signals were recorded in a memory instrument and subsequently transmitted telemetrically to Earth.

The characteristic of the amplifying system was constructed nonlinearly in order to register electrons falling perpendicular on the entire fluorescent screen with an energy of 10^4 ev at a current of $\sim 10^{-11}$ to 10^{-8} a/cm^2, this being in the case of an indicator with a thick foil.

The thin foil had small micropores which admitted solar light. Therefore, during an orientation towards the Sun the indicator having such a foil gave a reading on the middle scale. During the rotation of the satellite the photocurrent should have been symmetrical in relation to its maximum as a result of electromagnetic radiation of the Sun. It is necessary to know these conditions in order to evaluate the corpuscular reaction on the fluorescent screen having a thin foil.

An indicator with a thick foil did not yield any current signals during an orientation towards the Sun.

On May 15, 1958, intensive signals were registered by both indicators. Sometimes scaling was observed and signals were seldom absent near the threshold of sensitivity. Obviously, the amplitude of signals increases from equatorial to higher latitudes and with altitude. Many times, intensive signals appeared or disappeared suddenly over a period of 1 sec. The intensity of these signals varied.

As yet, the processing of the obtained material is not completed and it therefore cannot be compared with other observations. Consequently, we have no final opinion about it.

In principal, the registered signals may be explained as an irradiation of the fluorescent screens by ions,e.g., X-radiation, or electrons, if all these agents possess an energy of several kev to several hundred kev.

Since it is very difficult to contemplate a large proton force or X-radiation, preference should be given to such an agent which is connected with the lowest flux of energy. Therefore, the most attractive ones are the electrons which are not especially hard.

In cases where the radiation intensity of the fluorescent screens with a thin foil is somewhat larger than the one with screens having a thick foil, one may assume that the energy of the electrons does not exceed 10^4 ev and is possibly even less than that.

At the moment of scaling, the electron current exceeded 4×10^3 erg/sec cm^2 sterad; at the threshold of sensitivity it was about

3 erg/sec cm^2 sterad. Such an intensive irradiation undoubtedly will complicate the investigation of the solar X-radiation and the cosmic γ-radiation. The X-radiation propagated by the electrons may prove dangerous to living beings subjected to a lengthy travel through the upper atmosphere. In addition to this, powerful electron currents may heat up the upper atmosphere intensively, thereby increasing its altitude scale. This, undoubtedly, is interesting in the light of new information on the upper atmosphere.

At the present time it is too early to make any final hypothesis on the origin of the observed corpuscles. We will limit ourselves to some short remarks. The usual period of delay of geomagnetic disturbances in relation to the passage through the solar center of some characteristic formations of solar activity does not permit one to assume that electrons with an energy of several kev to several hundred kev might have been the original solar corpuscles. It is also difficult to assume that such electrons were created near the earth as a result of energy transformations of the initial corpuscles' protons, which traveled with velocities of about 2 x 10^2 cm/sec, since in order to explain the above-indicated energy fluxes (more than 4 x 10^3 erg/sec cm^2 sterad) a density of protons of about 4 x 10^3 would be required in the original fluxes; thus far, this condition has not been discovered during the study of hydrogen emissions of the polar light.

It is not without interest to point out the possibility of explaining the observed phenomenon as an acceleration of electrons of the outer atmosphere (in an electron conducting circuit formed along the magnetic force lines during its contact with the Earth's ionosphere) as a result of changing magnetic fields which are frozen into the solar corpuscular fluxes. We may expect in this case that harder electrons will fall in the polar regions, since a periphery with a large area is associated with the polar regions. The load of electron fluxes in the daytime can be explained by the increase of ionization on the borders of the exosphere, as a result of which the outer atmosphere is penetrated by great numbers of ionized particles, or by the activity of the magnetic variation p_c, which is more intensive in the daytime. By acquiring a certain velocity, the electrons may complete an oscillating movement along bent magnetic lines.

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10. THE STUDY OF SOFT COMPONENTS OF COSMIC RAYS BEYOND THE LIMITS OF THE ATMOSPHERE

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A. E. Shudakov

A. The Apparatus

To obtain data on protons from high altitudes, Sputnik III carried luminescent counters, which, as is known, are highly effective for the registration of photons (approximately 2 orders more effective than a Geiger counter).

The counter consisted of a 40 x 39-mm cylindrical crystal of sodium iodide and a photoamplifier with a photocathode having a 40-mm diameter. The following measurements were conducted with this device:

1. The counting rate of events, when the impulse corresponded to energy emission in the crystal of more than 35 kev.
2. The volume of anode current of the photoamplifier.
3. The current volume of the intermediate dynode.

The last two parameters characterize the full energy emission in the crystals in a unit of time.

A simultaneous measurement of anode and dynode fluxes makes it possible not only to determine the value of summaric ionization which takes place in the crystal (dynode flux) but also to evaluate the average portions that this ionization consists of. This appeared to be possible by taking advantage of the nonlinear effects in the region of the last electrodes of the photomultiplier, as a result of which the correlation between such anode and intermediate dynode fluxes depends on the value of separate explosions.

In order to measure correspondingly slow anode and dynode fluxes, an economical scheme was developed which operated on the principle of charge-accumulation on the condenser, which, after being charged to a determined potential, discharges through a neon bulb. This method enables one to measure fluxes up to 10^{-10}a. An impulse occurs after the discharge of the condenser and trips a trigger operating a relay; the contact position of the relay is transmitted by radio.

In order to measure the count rate, the impulses appearing on the last dynode of the photoamplifier are amplified by a two-cascade amplifier and proceed to the input of a dual cross scheme having a calculation coefficient of 4096. The threshold of the counter scheme corresponds to the energy emission in a crystal with 35 kev. The last trigger of the computation scheme controls the position of the corresponding relay. All electron schemes were made of semi-conductors. The overall power requirements of the device is 0.15 volts.

The radio transmitter "Mayak" used for the transmission of data has a frequency of 20 mc and operates continuously throughout the flight of the satellite. The transmitter "Mayak" relays information by changing the length of telegraphic signals. We have used the second and third signals (the second and third channels).

Figure 1 shows a block diagram of the instrument and a representation of telegraphic signals transmitted. The length of these signals depends on the resistance, which is ascribed to the input of the corresponding channel: when $R = 0$, $\tau = 50$ msec; when $R = 10$ kilohms, $\tau = 100$ msec; when $R = \infty$, $\tau = 150$ msec.

The change of the relay positions takes place after the determined charge is accumulated (relay 1 and 2) or during the accumulation of the determined number of impulses (relay 3). Thus, the intensity may be calculated according to $I = K/T$, where T is the period in which the relay remains in one position. For count rate measurement, $K_C = 2048$; during the measurement of ionization along an anode flux, $K_A = 2 \times 10^9$ ev; and during the measurement of ionization along the dynode flux, $K_D = 18 \times 9^9$ ev.

During calibration of the instrument, the coefficients K_A and K_D were measured by means of irradiation with γ rays of the isotope of mercury Hg^{203} (an energy of 279 kev). In this case the linear correlation between the energy of an explosion and the amplitude of an impulse on the output of the photomultiplier was not disturbed. The absorption along the amplitude of the output impulse takes place by an energy of 1--2 Mev. This means that during an irradiation of the instrument with initial cosmic rays only (in this case the explosion energy exceeds 20 Mev), one should expect that the measurements of the anode flux will yield an ionization value at least 10 times less than the measurements of the dynode flux, for which the effect of non-linearity practically does not exist.

B. The Processing of Results

The basic part of the information received in the form of signals from the radio transmitter "Mayak", was tape-recorded. The gathering of information is not as yet completed, and only a small part of the material has been processed. Most completely processed were the time intervals, which correspond to the flight of the satellite over the territory of the Soviet Union from May 15 to May 22 and from June 13 to June 16, 1958. Satellite recordings from the southern hemisphere were processed for June 7, 17, and 18. In addition, numerous separate recordings were made on the territory of the Soviet Union.

The processing of material has shown that for a period of more than one month complete information was transmitted continuously from the satellite's instrumentation in flight. Information on ionization fluxes was received for more than three months, since the energy requirements of these elements are insignificant and they had a large reserve of electrical power.

The results of measurements of count intensity have shown that the number of impulses in all cases exceeds the anticipated count rate of the initial cosmic rays by 10 times or more. This indicates that a basic contribution in the count intensity was given by the registration of photons. (This conclusion follows from a comparison of these results with data obtained by Geiger counters. We should also bear in mind that the luminescent counter was located inside the aluminum cover of this satellite, shielding the detector by a layer having the minimum mass of one g/cm^2.) At least a part of these photons should have been affected by a reverse photon flux which appears in the atmosphere under the influence of cosmic rays.

In Fig. 2 are represented typical examples of data processings conducted at one receiving point (Fig. 2a) and at two points (Fig. 2b), which are located in the Soviet Union. The lower curve represents the counting rate, the two upper curves the ionization (full energy emission in a crystal during 1 sec). The ionization measurements exceed the ionization caused by cosmic rays by several times. The fact that a large part of ionization is not connected with cosmic rays is explained by the small difference between the readings of dynode and anode fluxes. This proves that the "excess ionization" is given out in every case in small quantities.

However, the correlation between the count rate and ionization does not permit an explanation of this phenomenon, regardless of the energy of the falling radiation. The point is that even if the energy of the falling photons is lower than the threshold of registration according to the counting channel, the rate of counting should, in this case, also be 1 order higher than the observed one, since in addition to the intensity which is necessary for the creation of the observed anode fluxes, the imposition of impulses in time is of great importance.

This fact was verified under laboratory conditions during the irradiation of the instrument by X-rays. It appeared that the observed relation between the count rate and the anode fluxes may be received only by subjecting the photocathode to light from a fixed light source. Thus the "excess ionization" can be explained only by lengthy light exposure--phosphorescence of the NaJ (Tl) crystal.

The investigations of the crystals which we have used have shown that this phenomenon actually occurs. In Fig. 3 is shown one of the measured curves of fluorescence. The irradiation of the crystal by X-rays having an energy of 80 kev lasted in this case for a period of 40 minutes, whereby the intensity of irradiation corresponded to the energy emission in the crystal of 1.4×10^{12} ev/sec. Immediately after switch off of the X-ray tube, the current in the photomultiplier dropped by 140 times. The law of fluorescence may be more or less approximated by the sum of three exponents with τ = 15, 75, and 150 minutes. The full energy consumed by a lengthy fluorescence is about 1% of the energy of the short-lasting fluorescence.

Thus the "excess ionization" which was registered during the satellite's flight above the territory of the Soviet Union can basically be explained not by radiation in this region but by the peculiar "memory" of the crystal which was irradiated in the region of the equator, as will be shown below.

In Fig. 3a, synchronized oscillations of anode and dynode fluxes, with a period of about 2.5 minutes and a modulation depth of about 10% are distinctly visible. The period of these oscillations coincides with the periods of the satellite's rotation. The current oscillations were apparently caused by the influence of the Earth's magnetic field on the sensitivity of the photomultiplier. An effect of such a degree was anticipated on the basis of laboratory measurements. The fact that the counting rate does not experience such oscillations testifies that in the photospectrum only a small part can possess energies which are close to the threshold energy of 25 kev.

C. Electron Components of Cosmic Rays in the Polar Region

As can be seen in Fig. 2a the counting grade sharply increases at the determined moment. Such an effect is observed in all cases in which the satellite enters the region of about 60 deg northern latitude. During the satellite's travel from north to south an analogous drop of count intensity is observed. In Fig. 2b one of the cases is illustrated in which the beginning of the increase and, also, the drop were recorded on the same spiral.

It is not always possible to measure accurately the count in the region of its increase, since the intensity often goes beyond the possibility of radio transmission and the recounting scheme. In these cases, one can only say that the intensity is higher than a certain limit. The arrows in Fig. 2b serve this purpose.

It is obvious from Fig. 2a that a considerable increase of the count is not accompanied by a noticeable increase of ionization. Consequently, the energy of separated particles is very low. Therefore, by taking into account the thickness of the screen (1 g/cm^2), one should deduce that in the given case photons are registered.

However, a strong dependence of intensity on the geophysical coordinates can be observed only in the case of charged particles. The observed facts may be explained through the assumption that the counter registers the deceleration radiation of electrons which are fully absorbed by the shell of the satellite.

The analysis of many records similar to Fig. 2 has made it possible to establish the fact that, in the regions of increased count, on the average an insignificant increase of ionization can still be observed. By comparing this increase of ionization with the increase of the count rate it is possible to evaluate the energy of photons of deceleration radiation and, consequently, the energy of electrons. The energy of photons is about 100 kev or less. The indication "less" follows from the fact that in some cases only the lower limit is known for the intensity of the count. However, the energy of photons cannot be much less than 100 kev, since the registration threshold was 35 kev. Thus, the most probable value of the energy of electrons responsible for this effect is about 100 kev.

The current of these particles is characterized by considerable fluctuations. Therefore, the increase of ionization is sometimes entirely unnoticeable, and sometimes it appears to be considerable. However, the count intensity strongly increases in all cases.

Thus, the polar region is characterized by a constant presence of electron fluxes even if their intensity varies. By taking into account the effectiveness of registration of electrons by the retarded radiation, we evaluate the electron flux as 10^3 - 10^4 particles/cm^2 sec sterad.

Figure 4 represents a geographical chart in which the places where the satellite entered the high-intensity zone are indicated by points, and points of departure are indicated by crosses. The chart was composed from data for the period May 15 to 22. The fact that the crosses are located to the south possibly indicates that the effect depends on altitude, since the crosses correspond to the "reverse turns" and, consequently, to the high altitude of flight.

The high-intensity zone is not arranged symmetrically in relation to the magnetic pole. In order to illustrate this, a dotted line represents the geomagnetic parallel.

Further processing should supplement the data on the longitudinal effects and also explain the dependence on solar time. Of some interest also is the establishment of a correlation between the intensity of electron radiation and other geophysical phenomena.

For the time being, it is difficult to give a full interpretation of the observed electron components. It is not unlikely that these electrons accelerate near the Earth because of electrical fields which are similar to those assumed for the polar aurora. But it is also possible that the electron component comes from far away, i.e., from the Sun, and penetrates the Earth's magnetic field in spite of the low energy of its particles, if that field differs from the field of an ideal dipole.

D. High-Intensity Zone in the Region of the Equator

With the help of Geiger counters mounted on the American satellites α and γ, Dr. Van Allen and others have discovered that at a high altitude (about 1000 km) a very high intensity of charged particles can be observed. There is no accurate information available at the present time on the nature and energy of these particles. The basic information obtained from these experiments indicates that there exists a sharp intensity increase with altitude (the number of impulses in the Geiger counter increased 1000 times or more at high altitude).

In our measurements a flight altitude of 1850 km was reached. Because the high-altitude sector of the orbit is located in the southern hemisphere, records from this region have been greatly delayed, and at present only a few have been processed. These data indicate that, at an altitude of 1200 km, a very high intensity can actually be observed (the ionization in a crystal is greater by 3 orders than the ionization admitted by cosmic rays). However, it was discovered that, for this phenomenon, latitude is more characteristic than altitude.

In Fig. 5 is shown one of the recordings made in the southern region of South America. Along the abscissa axis the latitude is plotted, and along the ordinate axis the ionization in a crystal is plotted according to measurements of a dynode flux (accurate measurements of the anode flux and the rate of count is impossible in this region because of an overload of the telemetry system).

This drawing shows that the intensity increases sharply during a movement toward the equator, in spite of the fact that the flight altitude decreases from 1600 to 1100 km. Regardless of the type of mechanism of particle formation in the equator zone, it is obvious that the principal role in this effect is played by the factor of accumulation. This is convincingly testified to by the concentration of particles in the equatorial zone, where they could oscillate for a very long time at a sufficient altitude.

In this case, it is natural to expect that the plane of the geomagnetic equator, not the plane of the geographical equator, must serve as a symmetrical plane. As of now there are no data available from the equator which could answer this question, but the possibility exists that advantage could be taken of the continuous exposure luminescence of the crystal of NaI, which, during the measurements in the region of the Soviet Union, permitted one to obtain information on the type of energy being emitted by the crystal during the flight through the equatorial zone.

Direct measurements which are represented in Fig. 5, and measurements of the exposure energy over the regions of the Soviet Union actually correspond favorably with the experimentally obtained characteristics of exposure. Thus it is possible to utilize the numerous measurements from the territory of the Soviet Union in order to obtain equatorial data.

First of all, we receive a full amount of energy emitted in the crystal during one revolution of the satellite (the overwhelming part of this energy is emitted in the equatorial zone). On the average, this energy equals 2×10^{15} ev during one revolution, or 3×10^{11} ev/sec. If we assume that the mean period of flight in the zone of maximum intensity is about 10 minutes, the mean intensity of this zone will be 3×10^{12} ev/sec.

Secondly, it is possible to obtain information on the degree of stabilization of this value. It appears that if we talk about a constant intensity in the equatorial zone, measured during the flight of the satellite over the same parts of the Earth's sphere (such flights are repeated practically each day), the stability appears to be quite high. The dispersion is about 30%.

However, in a 24-hour period, because of the rotation of the Earth, the orbit changes its position in relation to its geographical coordinates and a systematic change of intensity can be observed. Figure 6 shows the relation of intensity to the rotation of the Earth. Since for one week the position of the satellite's orbit may, with sufficient accuracy, be considered a constant in space, the position of the orbit may be characterized by solar time. In Fig. 6, Moscow time is plotted along the abscissa axis. The ordinate axis shows the value of excess ionization, i.e., the value which is proportional to the energy of irradiation on the equator. For the construction of this graph, data from the time interval May 15 to 21 were used. As is obvious from this graph, the intensity undergoes systematic changes, depending on the time of day. The minimum, which was observed at 7:00 p.m., Moscow time, is at least 10 times lower than the maximum. If we should look at the position of the orbit at this moment, when the minimum intensity is observed, it appears that the southern part of the orbit is located at closest proximity to the magnetic pole. In this case, the southern part of the orbit, being located at high altitudes, passes at the greatest distance from the magnetic equator.

If we assume that the concentration of particles sharply increases during the approach to the geomagnetic equator and sharply increases with altitude, then, at least in a qualitative form, it is possible to explain the dependence of this effect upon the rotation of the Earth. By a more detailed examination it will be necessary to take into account not only the disagreement of the direction of the magnetic dipole with the axis of the Earth's rotation but also the shift of the dipole's center in relation to the center of the Earth.

However, it is already possible to make a hypothesis that the equatorial zone of high intensity spreads out symmetrically in relation to the magnetic pole of the Earth and is characterized by a strong concentration of density (of a flux of particles) on the plane of the magnetic equator.

Obviously, in such an equatorial zone, the ideal conditions for the oscillation of particles at the magnetic poles are realized, and it is possible that the escape is determined only by the ionization and radiation loss. This allows the particles to have such a long life span (on the order of 1 year) that even such a weak injection mechanism as is represented by the disintegration of neutrons which fly out of the atmosphere under the influence of cosmic rays will prove to be sufficient for the explanation of the observed intensity.

E. Research of the Solar γ Radiation

The presence of a great intensity of secondary photons which fly out of the atmosphere under the influence of cosmic rays and the presence of intensive electron fluxes in separate sections of the trajectory of the satellite considerably hamper the discovery of the weak γ radiation of the sun and other astronomical objects.

For the purpose of studying the γ radiation of the sun, we have investigated the change of photon intensity during several explosions on the sun on June 6, 1958. We also took advantage of the moments when the satellite passed through the border of the Earth's shadow, when it would have been possible to notice the presence of radiation. The effect was not discovered in this or any other case. We may only say that in these few cases the photon fluxes from the sun do not exceed a certain determined value.

These limits depend on the presumed photon energy:

Photon Energy, kev	Energy Flux, erg/cm^2 sec
10	1
30	10^{-4}
50	10^{-6}

It cannot be asserted that these limits will always be realized, since the statistic is still very small. However, it may be said that for a systematic investigation of this question it is obviously necessary to increase the sensitivity of the instrumentation considerably, possibly by the construction of a detector with a sensitivity in a small solid angle and with an automatic orientation toward the Sun.

In conclusion we would like to express our gratitude to all organizations that have sent us signal recordings from the radio transmitter "Mayak".

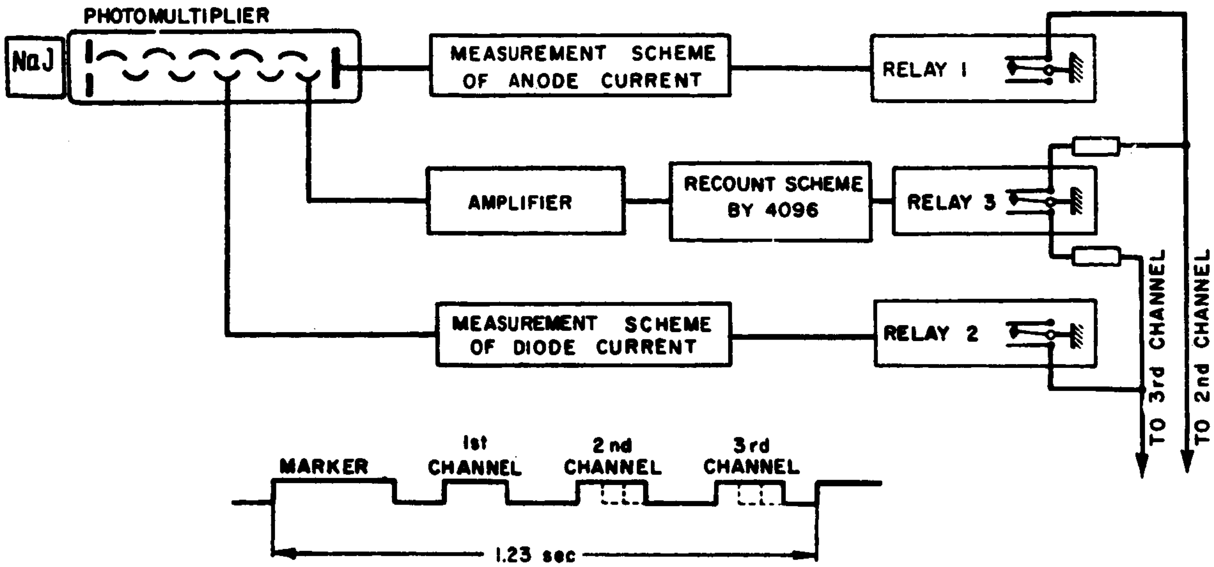

Fig. 1. Block Diagram of Instrument and View of Telegraphic Signals

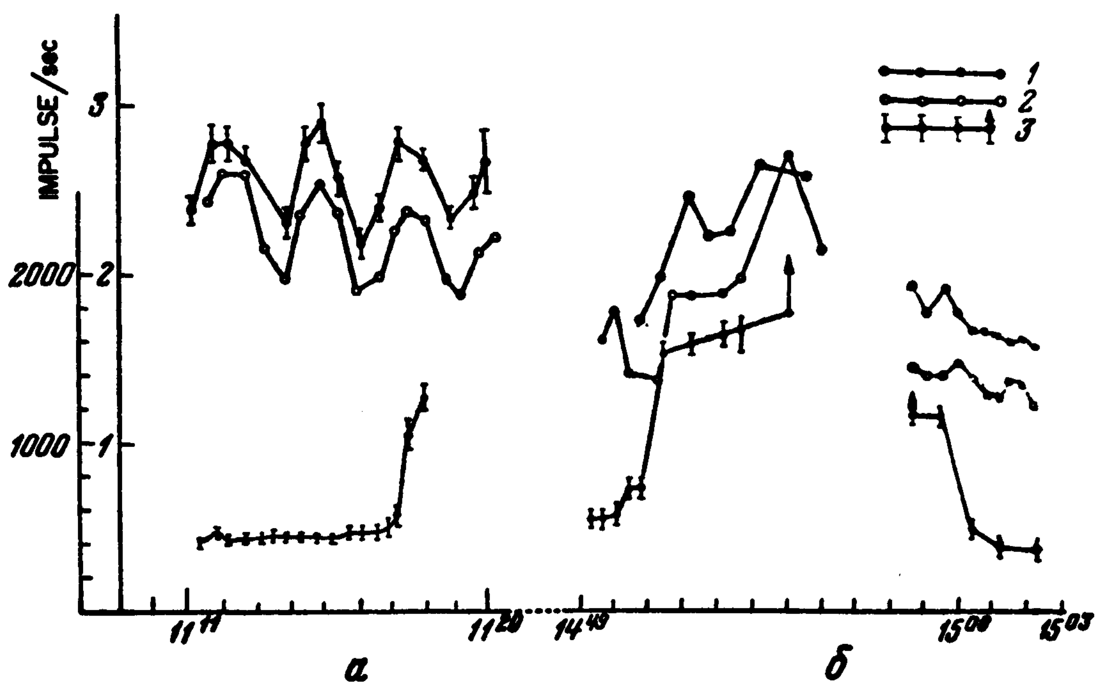

Fig. 2. Characteristic Record of Intensity Count and Ionization According to Data from Luminescence Counter on May 19, 1958 (Abscissa axis - Moscow time; ordinate axis - impulses/sec and energy discharge in 10^9 ev/sec)

1. Ionization according to measurements of diode current.
2. Ionization according to measurements of anode current.
3. Count intensity.

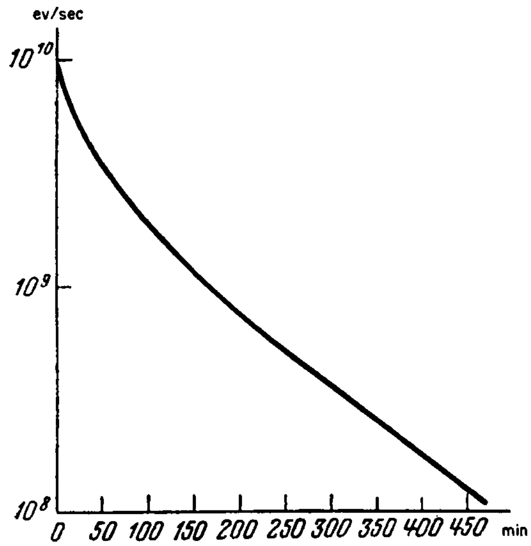

Fig. 3. Curve of Crystal Exposure (Ordinate axis - ionization in crystal which is necessary for the creation of observed exposure intensity)

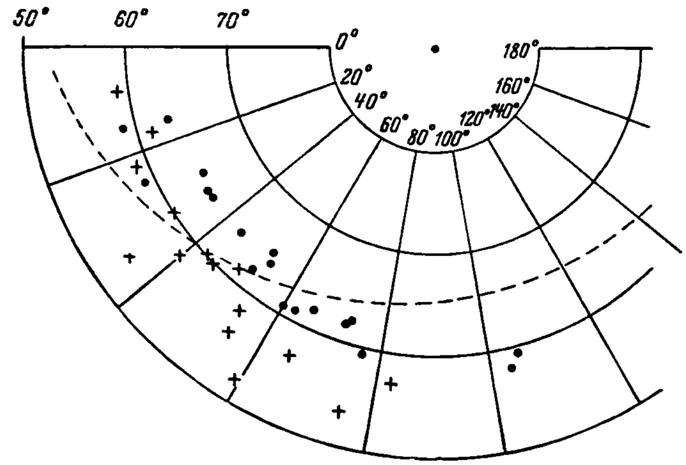

Fig. 4. Chart of Location of Points Where a Rapid Increase in Count Intensity (Circling) Takes Place (Crosses indicate satellite's exit from polar zone, where an increase in count intensity was observed)

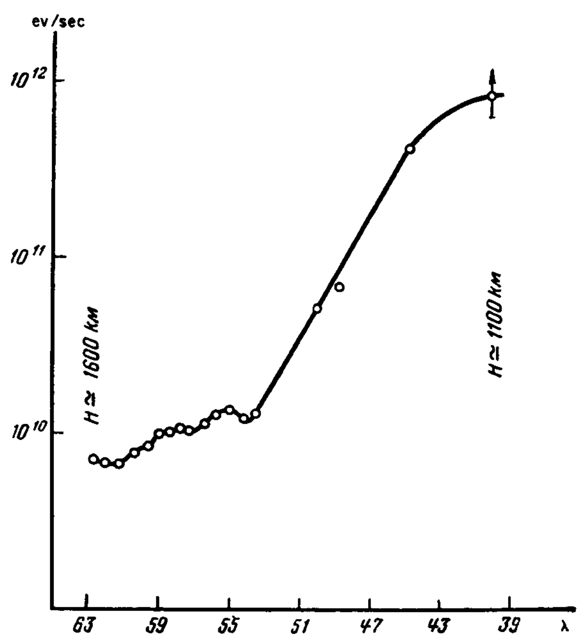

Fig. 5. One of Recordings Which Was Made in the Southern Hemisphere Within the Altitude Region of 1600-1100 km (Abscissa axis - Geographical latitude, southern); (ordinate axis - ionization in crystal according to measurements of diode current)

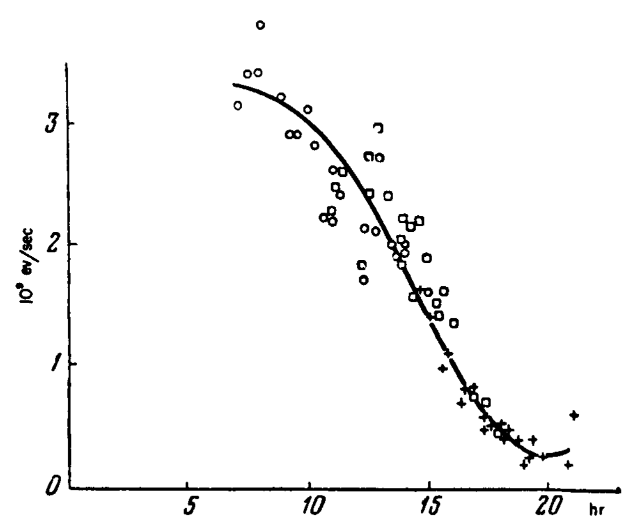

Fig. 6. Dependence of "Excess Ionization" on Time (Abscissa axis - Moscow time, in hours)

11. HEAVY NUCLEI IN PRIMARY COSMIC RADIATION

L. V. Kurnosova, L. A. Razorenov,
M. I. Fradkin

This paper will report the preliminary results of the experiment conducted with Sputnik III in order to clarify the question concerning the presence of atomic nuclei with a large Z number in the primary flux of cosmic radiation.

Up to the present time no reliable information has been available on the number of atomic nuclei with $Z > 30$ in the primary flux of cosmic rays. A series of papers has reported isolated cases of registration of heavy nuclei on photoemulsions which were exposed at high altitudes in the stratosphere (Ref. 1). On the basis of these results, the conclusion can be drawn that the flux of nuclei with $Z > 30$ is quite small. However, in the report by Igoda (Ref. 2), published in 1952, it was proven that in photoemulsions which were raised to an altitude of about 37 km, a comparatively large number of heavy nuclei was recorded. According to the estimates by Igoda, a flux of nuclei with $Z > 34$ consisted of approximately 30% of the nuclei flux of the Fe, Co, and Ni group. The results of this work furnished a basis for the assumption that there exists a noticeable flux of very heavy nuclei beyond the atmospheric limits.

If such a conclusion had been confirmed, this would have been of essential significance for the theory of the origin of cosmic rays. Actually, on the average, the distribution of chemical elements with $Z > 30$ is very small throughout the universe, and it is reasonable to assume that in cosmic rays the portion of corresponding nuclei with

Z > 30 should also be small. In addition, owing to a large section of interaction, the run of heavy nuclei in the interastral environment is considerably less than the run of light nuclei. Therefore, the correlation between the fluxes of heavy and light nuclei should vary in favor of light nuclei.

As part of the IGY program, the Soviet Union proposes to conduct a series of investigations of nuclear components of cosmic radiation with the help of artificial Earth satellites (Ref. 3). The instrument which was installed on Sputnik III was designed for the registration of nuclei with X > 15 (first threshold of the installation's wear) and Z > 30 (second threshold of the installation's wear).

The block diagram of the instrument is shown in Fig. 1. The operation of the instrument is based on the utilization of the Vavilov-Cherenkov effect. On the left side is shown a Cherenkov counter. This counter consists of a photo-multiplier with a photo-cathode of 26-mm diameter and a detector. The detector is a plexiglass cylinder, 26 mm in diameter and 26 mm high. The optical contact between the detector and multiplier was accomplished with Canadian balsam. The photoelectron multiplier (FEU) was powered by a battery with an over-all intensity of 940 volts, by which the voltage for the dynodes was supplied by means of taps at each 94 volts.

The Cherenkov counter has registered atomic nuclei with a kinetic energy of more than 3×10^8 ev/nucleon. Particles which impacted on the detector from any direction were registered during their run in the detector for a sufficient period of time.

The impulse from the FEU output was sent through an emission repeater on two amplifier channels with different thresholds. Trigger cells were located at the channel outputs. The trigger outputs were fed to the radio-telemetry system. The various states of the trigger cells corresponded to a different value of constant voltage which was fed to the radio-telemetry system. If the impulse of the photoelectron multiplier exceeded the volume of the threshold, the trigger cell began to operate and the output voltage of the instrument was changed rapidly. By the number of such changes on the output voltage it was possible to determine the number of registered nuclear currents.

A photograph of the open instrument is shown in Fig. 2; Fig. 3 shows the main diagram of the instrument. (The radio-circuit of the instrument was developed by G. S. Dragun, to whom the authors of this paper express their gratitude.) A curve of amplitudinal distribution from cosmic ray μ-mesons was taken during the ground testing of the instrument.

The average obtained impulse from mesons appeared to be the resistance point for the establishment of a threshold of operation for the electron parts of the scheme. The first threshold was tuned to the impulse which exceeded the average impulse of the meson by approximately 300 times, which corresponds to the nuclei with $Z \approx 15$. Such a choice of a threshold is a result of the fact that the nuclear flux with $Z \geq 15$ is comparatively large, and the inaccuracy in the establishment of the threshold in this region of the Z values will show up slightly on the registered flux. The latter circumstance is connected with the fact that the main contributions in the nuclear flux with $Z > 15$ are made by the nuclei of the Fe, Co, Ni group, with a charge differing strongly from $Z = 15$. However, among the nuclei with $Z < 15$, the most popular are the nuclei of the C, N, O group, the charge of which is much less than 15.

For the establishment of the first threshold, an impulse-type light source was used which yielded an impulse on the output of the photoelectron amplifier approximately 300 times larger than the impulse from the meson. The establishment of the second threshold was accomplished with a pulse generator.

It should be noted that, as a result of a comparatively wide amplitude distribution of impulses from μ-mesons, the determination of the mean value from a meson impulse and the accurate adjustment of the thresholds become more difficult.

Taking into account the inaccuracy of the threshold adjustment and also the errors caused by the difference between the photoelectron amplifier characteristic and the linear characteristic and by a certain dependence of the installation effectiveness on the charge of the particles, it should be considered that the threshold adjustments correspond to the Z values which are located in the intervals $15 \div 20$ and $30 \div 40$ for the first and second thresholds, respectively.

Results were obtained on the basis of preliminary data processing on the operation of the instrument over a period of 9 days. The number of nuclei with $Z > 15 \div 20$ was estimated for separate time intervals with a total duration of 3 hours. The average number of nuclei with $Z > 15 \div 20$ was 1.22 ± 0.08 per minute. Only one transition of output voltage levels was recorded; it corresponded to the registration of a nucleus with $Z > 30$. This transition took place during the period of the indicated time intervals.

It should be mentioned that if for a certain time interval the instrument has registered an odd number of nuclei with $Z > 30 \div 40$, this circumstance will be established during the processing of separate intervals, since in this case the state of the corresponding trigger cell will undergo a change and the output voltage in the neighboring intervals will vary. If the number of nuclei registered in the period between the time intervals is even, the state of the triggered cell will remain the same, and during the processing it will be impossible to establish the fact of the instrument's operation.

However, there is very little probability that the number of cases will be even in each period. Assuming that there are equal numbers of intervals with even- and odd-numbered transitions, it is possible to estimate the maximum number of nuclei with $Z > 30 \div 40$ that passed through the installation. Such an estimate shows that for a period of 9 days not more than 1 to 3 nuclei with $Z > 30 \div 40$ have passed through the Cherenkov counter. Consequently, the correlation between the fluxes of these nuclear groups is less than 0.01 to 0.03%.

The obtained results permit one to make only a superficial evaluation of the relations of nuclear fluxes with $Z > 15 \div 20$ and with $Z > 30 \div 40$. From the data on the distribution of elements in the universe (Ref. 4) it is possible to find the relation of distribution of the corresponding elements:

$$P(Z > 30)/P(Z > 15) = 1.3 \times 10^{-4}$$

and

$$P(Z > 40)/P(Z > 20) = 6.5 \times 10^{-4}$$

A comparison of an experimentally obtained result with regard to distribution indicates that the value of the fluxes is not contradictory to the contemporary ideas on the acceleration of cosmic ray particles and their movement throughout the interastral space.

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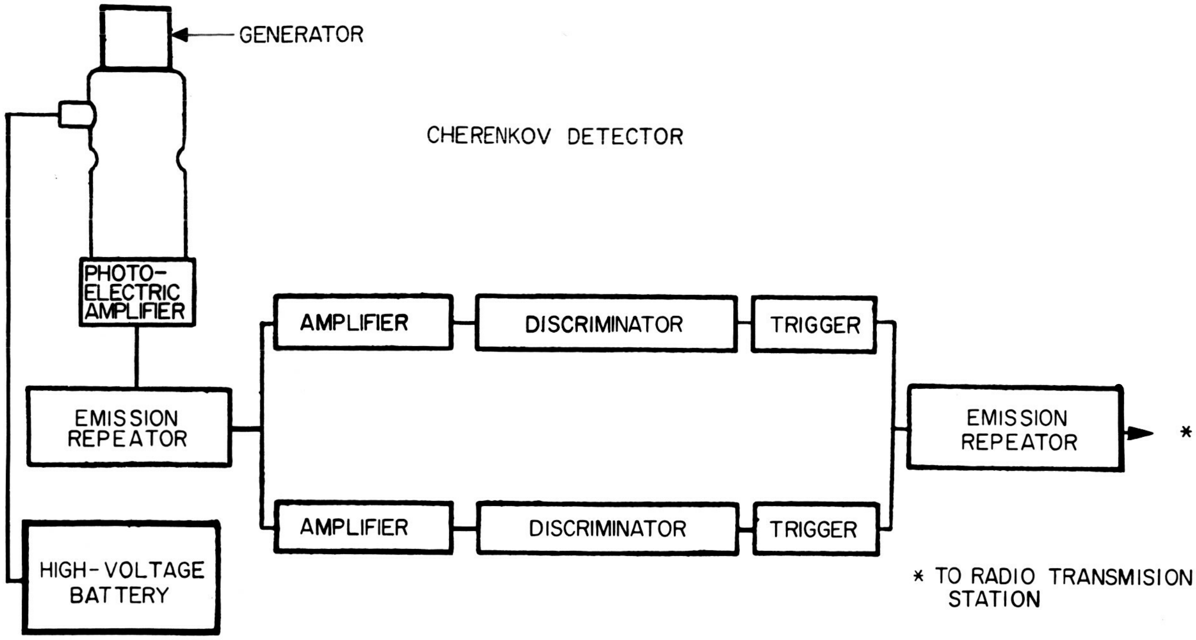

Fig. 1. Block Diagram of Installation

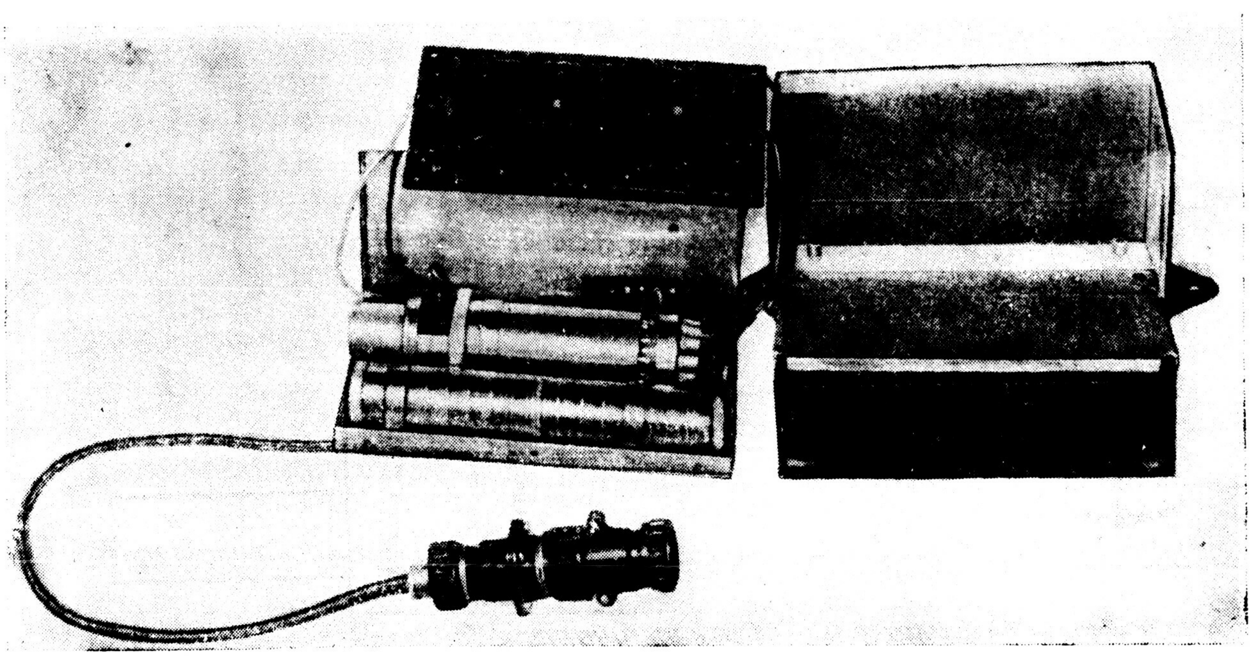

Fig. 2. External View of Installation

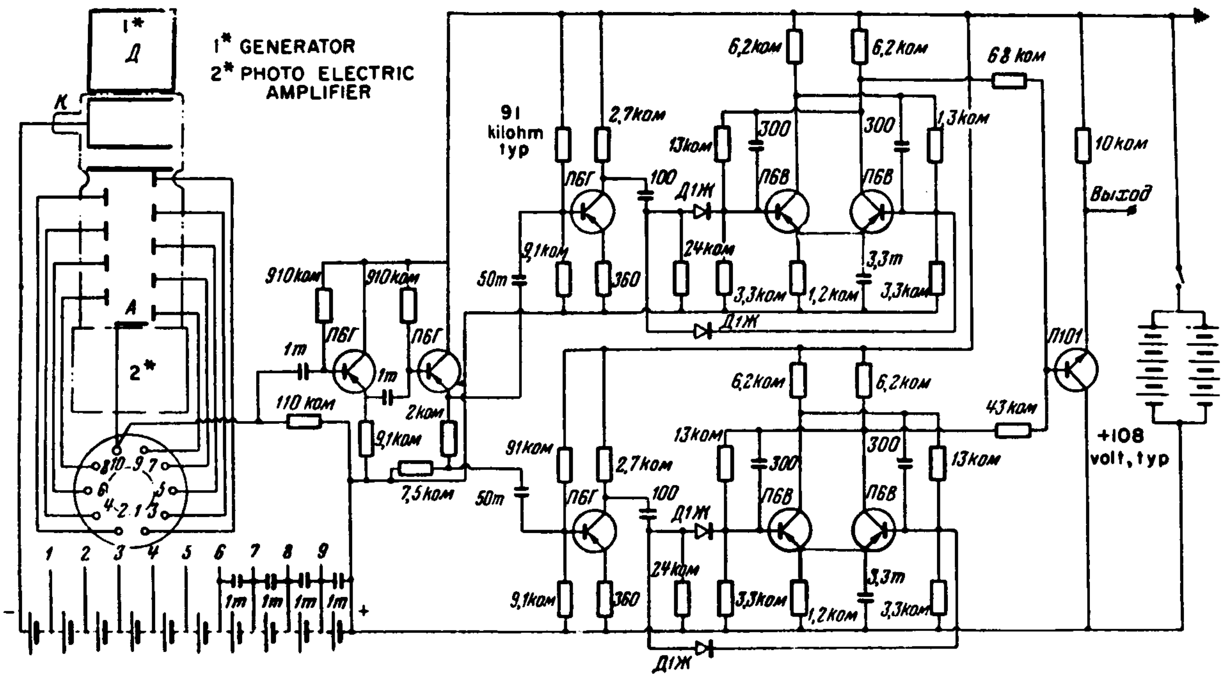

Fig. 3. Principle Diagram of Installation

12. SOLAR BATTERIES

V. S. Vavilov, A. P. Landsman,
D. K. Subashyev

A. Possibilities for Further Increase of the Efficiency Factor of Solar Batteries

The principle of operation of solar batteries, i.e., that of semiconductive photoelements of a high effectiveness, has been described in detail in the literature (Refs. 1 and 2). Hence it is feasible, without further delay, to examine some of the recently obtained data on the properties of silicone photoelements, which are now used on artificial Earth satellites. In addition, we will investigate some possibilities for improving the properties of existing solar batteries.

All the following data, which refers to silicone photocells, recognizes the fact that, in its combination of properties, silicone is a nearly ideal material for semiconductor convertors of solar energy. It can be stated with great certainty that during future years the principal efforts of physicists and engineers in this field will be focused on the study and improvement of silicone devices. Furthermore, with silicone it may be found expedient to use intermetallic compounds, particularly CaAs, InP, CdTe, and AlSb. We shall concern ourselves with some problems which are essential for the operation of solar batteries.

1. Stability of operations. The basis of a semiconductive transformation of radiation energy is an artificially obtained P-N transition. It has been proven that P-N transitions obtained with the method of diffusion of phosphorus (Ref. 4), boron (Ref. 5),

or antimony (Ref. 6) should not, even at the highest operating temperature (200°C), change properties in the course of any tangible period of time, e.g., hundreds of years. This characteristic is related to the fact that atoms of the admixture which form P-N transitions and which are introduced at a very high temperature are strongly bound with the atoms in the silicone crystal lattice in which an absorption of light takes place.

Another factor which contributes to the stability of silicone photocell properties is the presence on the crystal surface of a protective film of silicone dioxide, which is light, transparent, and very stable. In this regard, silicone differs advantageously from germanium, whose surface properties depend strongly on the pressure of the surrounding atmosphere, the composition of the gas medium, and humidity. It differs also from selenium and cadmium sulphate, which are used in valve-type photoelements. Experiments which were conducted by the authors have demonstrated that the characteristics of silicone photoelements remain unchanged not only during a lengthy stay in a vacuum but also during bombardment by electrons with an energy of up to 30 kw (Ref. 7). However, it should be pointed out that ion bombardments, which disrupt the SiO_2 layer and disintegrate the silicone itself, influence the functioning of the photocell, increasing thereby the superficial velocity of the recombinations of electrons and holes and decreasing the utilization coefficient of α. ($\alpha = I/qN' h\nu$, where I is a photoflux of a short circuit, q is the electron charge, and $N' h\nu$ is the number of photons absorbed per unit of time.) In connection with this, the elements of solar batteries should be protected from collisions with micro-meteorites.

2. Temperature dependence, efficiency factor, and thermal conditions. The increase in solar battery efficiency with reduction in temperature, which has been expected on the basis of theoretical consideration, has been observed in all cases known to us (Ref. 4). Of great interest is the possibility of obtaining increased powers from the same working area of the battery by concentrating light with the help of extremely lightweight mirrors. Available experimental data (Ref. 8) indicate that, with good heat dissipation, i.e., with silicone maintained at a temperature up to 25°C, it is possible to obtain a tripled electric power from 1 m^2 of working area (which is up to 180 watt/m^2 with an incident power of 1 kw/m^2) with a sixfold concentration of light. It is understood that a concentration can be used only with proper heat dissipation. In the case of nonoriented satellites, light concentrations by means of mirrors are quite difficult.

3. Concerning the approach to the theoretical limits of efficiency. As is known, the efficiency of the best elements of solar batteries does not exceed 13% (Ref. 9); and for the batteries as a whole the value is much lower. In the following material we will investigate the possibilities connected with physical processes which take place in silicone and on its surface, the utilization of which, it seems to us, can possibly help to essentially increase efficiency when approaching the limit calculated in some propositions by Prince (Ref. 2) and which is about 23% for T = 300°K (which means that for conditions outside of the atmosphere it amounts to more than 300 watts of electric power from 1 m^2).

a) It has been established that the length of an electron diffusion which determines the "utilization coefficient" for longwave light ($h\nu < 2.5$ ev) following heat treatment in the presence of phosphorus drops from 200--800 to 20--50 microns (Refs. 8 and 10). It was proven that the phosphorus in itself does not belong to the recomposing mixtures which sharply decrease the life span and length of diffusion of the carrier. An important problem before us is to explain the reasons for the drop in the length of diffusion. The protection of the silicone properties, which are close to the original, will make it possible to improve, by several times, the utilization of longwave light (Fig. 1).

b) Modern silicone photoelements possess a relatively low sensitivity in the shortwave part of the spectrum, beginning with yellow light (Fig. 1). This is characteristic for photoelements but not for the photoionization process in silicone itself. The quantum yield, which is the number of photoelectrons per 1 absorbed photon, equals 1 unit in the region of the value $h\nu = 1.1/32$ ev. It was recently demonstrated (Ref. 11) that when $h\nu > 3.2$ ev the quantum yield increases, this being due to the impact ionization resulting from the excess energy of photoelectrons. In such a manner the utilization of shortwave parts of the spectrum represents an important assignment.

However, its solution is encountered by complicated problems of decreasing distribution of P-N transitions and lowering the speed of superficial recomposition.

In Fig. 1 we have compared the spectral characteristics of typical modern silicone elements and the "ideal" characteristics for a case of complete accumulation of photoelectrons and holes. In Fig. 2 the corresponding portions of the photo-current which originated during the absorption of the solar radiation in a typical element of a solar battery (lower curve) and in an ideal silicone photoelement (upper curve) are compared.

c) The third method for increasing efficiency is the trans-illumination of the silicone surface. In the region of silicone waves with a wave length of 1/0.25 microns, the reflection coefficient R exceeds 30% and increases with the decrease of the wave length (when $\lambda = 0.25$ microns, $R \approx 70\%$) (Refs. 11 and 12). By reducing the reflection coefficient without increasing the surface recomposition rate in the process, it is possible to increase the effectiveness of a photoelement.

It has been demonstrated that a considerable clarification of the silicone surface can be achieved through oxidation, i.e., by the creation of a strong and transparent film of S_iO_2 of sufficient thickness (Ref. 13).

The thickness of the film and, consequently, the position of the minimum reflection coefficient can be regulated in accordance with the properties of the photoelement and the spectral composition of the utilized light. The reflection coefficients of pure silicone and the clarified surface are shown in Fig. 3. The relative increase of the photocurrent for the solar spectrum amounts to 20--25%.

B. The Operation of Solar Batteries Aboard Sputnik III

The conducting of prolonged scientific observations with the help of artificial Earth satellites made it necessary to considerably increase the weight of the power sources. Positive results of an experiment on the direct transformation of solar energy into electrical energy outside of the Earth's atmosphere, which is being accomplished on Sputnik III, permit us to hope that the problem of a power supply for scientific instrumentation aboard satellites has been solved.

In examining the question as to the possibilities of using solar batteries as power sources for artificial satellites, one can cite two principal causes for their possible malfunctioning or loss of efficiency during operation in cosmic space:

1. High temperature of solar batteries as a result of prolonged solar irradiation.
2. Abrasion of the surface of solar batteries or of the protective surface which covers the batteries by micrometeorites (meteoric erosions).

Ground condition investigations could not supply a definite answer to these questions. In connection with this, Sputnik III carries experimental solar batteries which were expected to clarify these primary questions; in addition, Sputnik III carried solar batteries which were installed as power supplies for the radio transmitter "Mayak."

The experimental solar units are located on two opposite sides of the satellite's body. Each unit consists of two solar batteries with various coatings and a resistor thermometer with an inclined plate of monocrystallic silicone. Two batteries, serving as standards, are covered with frosted glass and are located one in each unit. One battery is unprotected; the other is covered with polished glass.

In the presence of meteor erosion the properties of the batteries protected by frosted glass should not deteriorate with time. The battery covered with ordinary glass will gradually approach, by the value of its emitted current, the battery with frosted glass, and the unprotected battery should cease working altogether after the thin superficial layer is wiped off. The temperature units have made it possible to consider the influence of the temperature and judge its fluctuations.

Deciphering of films covering the first days of the unit's operation has enabled us to obtain information on the temperature of the unit. In accordance with calculations, the average temperature of the silicone converters varied between 16 and 30°C (see Table 1) during the first days, which should be related in part to the special treatment of the bodies of solar batteries, which increases the coefficient of its superficial radiation. Taking into consideration the very insignificant heat conduction between the unit and the body of the satellite, it is possible, on the basis of available materials, to affirm that by a rationally executed construction there is no need to fear malfunctioning of photoconverters due to overheating.

Preliminary processing of data connected with meteoric erosions does not permit us to draw any quantitative conclusions yet. However, judging from the functioning of the experimental solar battery which is not protected by a glass surface, abrasion takes place rather slowly. More time will evidently be necessary in order to derive quantitative results.

Preliminary conclusions can also be drawn concerning the effect of cosmic radiation. The operation of the "Mayak" radio transmitter over a period of more than 6 months confirms the fact that cosmic rays do not represent any danger to solar batteries. (Available data on damages to the silicone structure from high-speed particles and on the influence of these damages on the life span of the carrier's conductivity and optical properties are the basis for the consideration that cosmic radiation cannot affect the operation of solar batteries.)

Simultaneously with experiments conducted with a satellite for the purpose of explaining the influence of various factors on the functioning of silicone converters, a large solar battery was constructed to power the "Mayak" transmitter. In designing the batteries the following features were taken into account:

1. The undesirability of a buffer connection of the solar battery with storage batteries.
2. The rotation of the satellite and, consequently, the need for a power supply.
3. Shunting of the illuminated parts of the batteries by the nonilluminated sections.

As a result, the following constructive formulation was adopted: The solar battery was placed in the form of separate sections on the surface of the body. Four small sections were installed on the forward part, four sections on the side of the surface, and one section on the rear end of the satellite. All sections were connected with each other in parallel by diodes. Such a scheme eliminates the shunting of the illuminated sections of the battery by nonilluminated sections and secures the normal function regardless of the satellite's orientation in relation to the sun.

The radio transmitter was powered by solar batteries only while the satellite was exposed to solar rays. During the satellite's movement in the shadow of the earth, the transmitter was powered by electrochemical sources. Switching from one method to the other was accomplished automatically when the electrochemical batteries or accumulators ceased to operate; upon termination of their life span the solar batteries will continue to operate during illumination by the Sun. An essential shortcoming of this system is the necessity of using the solar batteries in a nonoptimum regime caused by a sharp variation in load during the transmitter's operation. For this reason a power reserve is provided in the batteries. In the future the need for such a reserve will cease, since solar batteries will be used in conjunction with the buffer storage battery.

Information on the functioning of the "Mayak" power sources is transmitted through its radio channel by varying the length of telegraphic messages. The following coding of signals is used in this process. When the radio transmitter is powered by solar batteries, the duration of the first telegraphic transmission following the marker transmission of 300 msec is 150 msec, and when the power comes from electrochemical sources it is 50 msec.

The continuous work of the "Mayak" transmitter over a period of 6 months permits one to draw the important conclusion that high-powered solar batteries are already utilized in a practical manner on artificial Earth satellites.

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Table 1. Daily Average Surface Temperature (°C) of Solar Batteries During the First 17 Days of the Satellite's Flight

Experimental Solar Battery	Day of the Month (May)																
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	24	30	25	24	21	21	22	26	20	25	23	24	21	24	16	24	22
2	25	25	26	27	25	24	23	25	18	23	25	28	23	26	27	21	22

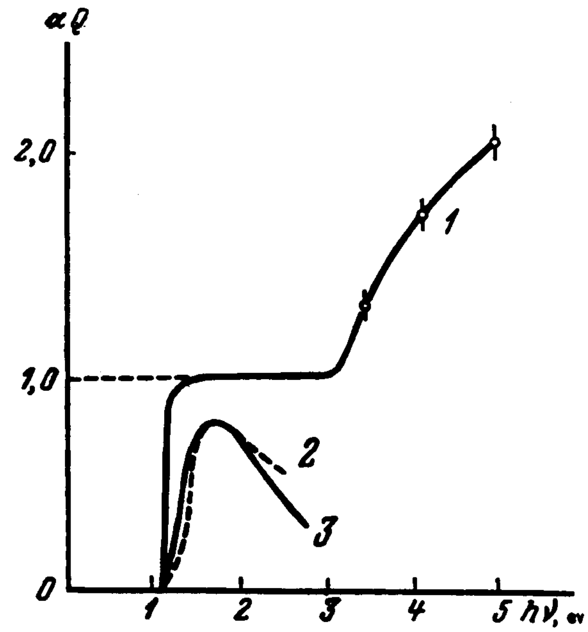

Fig. 1. Comparison of Spectral Characteristics of Contemporary Silicone Photoelements with the "Ideal" Characteristic
(1- utilization of photons for an ideal silicone photoelement: quantititive exit of photoionization; 2- photoelement "Bell"; 3- experimental photoelement FIAN)

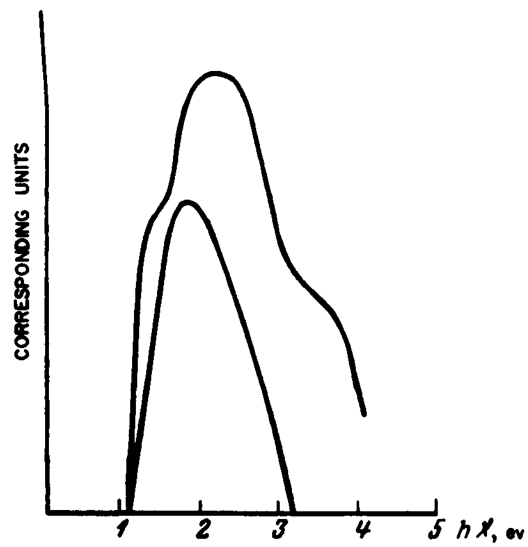

Fig. 2. Comparison of a Relative Portion of Photo-Current Which Appears During the Absorption of Solar Radiation in a Typical Element of a Solar Battery, Lower Curve, and in an Ideal Silicone Photoelement, Upper Curve

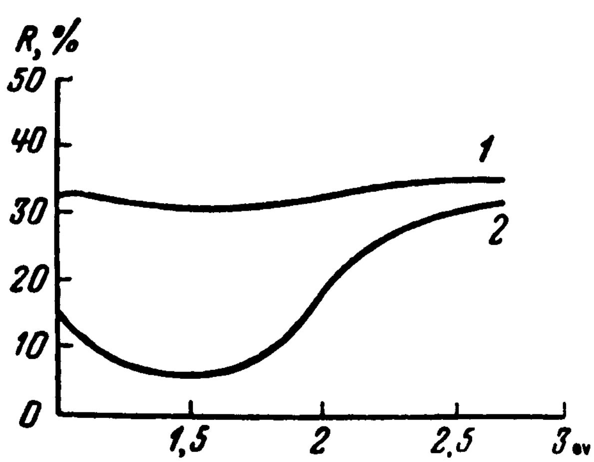

Fig. 3. Reflection Coefficients of Pure Silicone, Curve 1, and Transparency of Surface, Curve 2

13. ACOUSTICAL METHOD FOR THE MEASUREMENT OF MECHANICAL PARAMETERS OF METEORITES

M. A. Isakovitch, N. A. Roy

For several years direct attempts have been made to discover meteorites with the help of acoustical instruments installed on rockets. However, the applied instruments have made it possible to conduct only a count of particles, and, in principle, they did not enable measurements of their mechanical parameters, e.g., the impulse or energy of the particles. This instrumentation includes a piezo transducer made of a piezo crystal, on the output of which a voltage occurs when the instrument is hit by a meteorite. Such instruments, utilizing piezo elements, are characterized by low weight, simplicity, and a relatively high sensitivity, but they do not yield a uniform correspondence between the mechanical parameters of the meteorite and the electric signal. Therefore, a transducer of this type cannot be used as a measuring instrument. In particular, the fall of a particle on various parts of the surface of the transducer causes the formation of elastic waves of various forms in the transducer. The deformation of a crystal in its periodical functions and, consequently, the electric tensions which are determined by it will differ for the same meteorites impacting at various points on the transducer.

Thus, in order to determine the mechanical parameter of meteorites directly by the electrical tension on the outlet of the transducer, it is necessary first of all to secure a standard of the deformation of the piezo elements. This will change only the amplitude of the obtained deformation.

Furthermore, the question arises as to which mechanical parameters of a meteorite can be measured. Complete data could have been obtained during a measurement of the mass and velocity of the meteorite (or any two independent combinations of these values). However, the mass or velocity does not submit to direct measurements. The impulse of the particles cannot be measured, since during a collision with the surface of the transducer a local explosion occurs by which the impulse of the ejected material of the transducer considerably surpasses the impulse of the particle itself and thus camouflages the particle. An impact takes place with a "coefficient of restitution" which is larger than a unit. However, according to the theory of K. P. Stanyukevitch, the impulse of a material ejected during an explosion is synonymously connected with the kinetic energy of the particle causing the explosion. In such a manner, by measuring the impulse obtained by the transducer, it is possible to measure also the energy of the particle.

In connection with the stated considerations, we have proposed an acoustical transducer which reacts only to an impulse being received during an impact of a particle, i.e., a ballistic transducer. Such a transducer must therefore measure the kinetic energy of a particle.

We shall mention, however, that the correlation between the ejection impulse and the energy of the particle should be investigated in more detail. The ballistic transducer should have a separation of the element of mass and the element of elasticity. The deflection of the elastic element must cause a deformation of sensitivity in the piezo element which will also create voltage. The mechanical system should have a sufficiently low frequency so that the oscillations inside the element mass will practically quiet down for a period less than the natural period of the instrument. In such an instrument the elastic element together with the sensitive piezo element will be under a quasi-static regime, and their deformation will therefore always be standard in form. However, the regime of operation of the transducer depends on the place of impact of a particle on the elements of mass (diaphragm of the transducer): when the impact occurs off the center of gravity, the diaphragm will receive an initial rotation in addition to the initial velocity. It is necessary to apply several sensitive elements, connected in parallel, in order to prevent this condition from damaging the sensitivity of the instrument.

An absolute calibration of the transducer can be accomplished by means of observation of the recoil of a ball with a known mass being dropped from a determined height. Actually, just as in the case of a meteorite impact, the transducer operates like a ballistic device insofar as real values of impact time are concerned.

Finally, in order to register particles of minimum dimensions, it is necessary to increase the sensitivity of the transducer as much as possible. This can be accomplished by the application of an "offset transformer" for the piezo elements.

All described ideas and the corresponding schemes of construction were the basis for the transducers which were utilized to conduct some measurements of meteorite parameters. The description of the device, the results of observation, and a short abstract of the considerations here included were quoted herein from the paper "The

Investigation of Micro Meteorites With the Help of Rockets and Satellites," by O. V. Komissarov, T. N, Nazarova, L. N. Neuedoz, S. M. Poloskov, and L. Z. Rusakov.